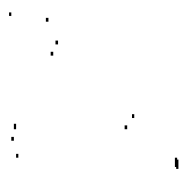


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THE HISTORY OF
A LUMP OF COAL

From the Pit's Mouth

TO

A BONNET RIBBON.

BY

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"Science in a Nutshell," &c., &c.*

WITH ILLUSTRATIONS.

'Sermons in stones, and good in everything.'—SHAKESPEARE.

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PREFACE.



If the great poet who wrote of "Sermons in Stones" could witness our day, and the marvellous revelations which Science has made since his own time, how truly would he see the practical verification of his poetic fancy! Beyond its ordinary uses as fuel, and in the production of artificial illumination, there lies a history in Coal which has been gradually, but faithfully, revealed to man by the steady, persevering, and ceaseless labours of the servants of Science.

The aim of the following pages is to place before the reader, in a simple and condensed form, all the most interesting facts about Coal and its products which have come to light (without intending a pun) since the discovery of gas illumination.

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THE HISTORY OF A LUMP OF COAL.

I.

Origin of Coal. Will our Coal last for ever?

One of the greatest of modern philosophers, Michael Faraday, said :—" There is no better, there is no more open door, by which you can enter into the study of Natural Philosophy than by considering the physical phenomena of A CANDLE." The same observation applies with equal force to A LUMP OF COAL.

There is nothing very remarkable in a lump of coal, you will say. It is black and shining, as far as appearance goes, and if it be a good sort of coal, it will make a cheerful fire, causing you to feel cosy and comfortable and happy. And of course we all know that coke and gas come from coal, and also tar. This is common knowledge, and therefore not very interesting matter. If we go a little farther, however, we shall find that of all substances which are dug out of the earth, coal is one of the most remarkable in the vast extent of its usefulness to man.

As to the origin of coal, it has been clearly established, by the observations of our great scientists, that it is *the fossil remains of trees and plants* which flourished upon the earth's

surface many thousand years ago, and many species of these plants do not now exist, so far as we know. The impressions of leaves, fronds of ferns, and many varieties of extinct vegetation, some of them of a reed-like form, have been from time to time discovered in our coalfields.

Regarding the vegetable origin of coal, the late Dr. Mantell wrote: "Although the vegetable origin of all coal will not admit of question, yet evidence of the original structure is not always attainable. The most perfect bituminous coal has undergone a complete liquefaction; and if any portions of organisation remain, they appear as if imbedded in a pure bituminous mass. The slaty coal generally preserves traces of cellular or vascular tissue; and the spiral vessels and dotted cells indicating coniferous structure, which may readily be detected by the aid of the microscope, in chips or slices. In many examples the cells are filled with an amber-coloured resinous substance; in others, the organisation is so well preserved that on the surface exposed by cracking from heat, vascular tissues, spiral vessels, and cells studded with glands may be detected. Even in the white ashes left after the combustion of the coal, traces of the spiral vessels are discernible by high magnifying power.

"Some beds of coal appear to be wholly composed of minute leaves or disintegrated foliage; for if a mass, recently extracted from the mine, be split asunder, the exposed surfaces are found covered with delicate pellicles of carbonised leaves and fibres, matted together; and flake after flake may be pulled off through a thickness of many inches, and the same structure be apparent.

"Rarely are any large trunks or branches observable in the coal, but the appearance is that of an immense deposit of delicate foliage, shed and accumulated in a forest (as may be observable in existing pine districts) and consolidated by great

pressure while undergoing that peculiar formation by which vegetable matter is changed into a carbonaceous mass."

These evidences of the vegetable origin of coal, in my humble opinion, prove that at one period of the world's marvellous history a great deluge *must have occurred*. It may be asked, How did the deluge influence the formation of coal? Without attempting to assert that it was so, may we not venture to account for the formation of coal in this wise? During the Great Deluge, so beautifully described in the seventh chapter of the Book of Genesis, the earth was covered with water, even the summit of the highest mountains being hidden from sight. It is but reasonable to suppose that while this terrible effect of Divine wrath was being consummated, countless millions of trees and every variety of plant which had grown upon the earth up to that period became uprooted by the force of the devastating tempest, and floated upon the vast accumulating waters until, at the Divine command, the tempest ceased to rage and the waters in course of time subsided.

During the subsidence of the waters the vast masses of vegetable matter would become deposited in the valleys and low-lying parts of the earth, and become enveloped in the *débris* of disintegrated rocks and loosened earthy matters. In process of time these vegetable masses, being thus protected from the oxidising influence of the air (which we know assists decay), would undergo those slow changes and transformations so remarkable in the grand operations of Nature, until, finally, the former vegetable growth of ages became converted into vast beds of petrified or fossilised organic matter, which we now call coal, and which, more especially in this portion of the great globe, has proved so serviceable as fuel for the various purposes of civilised life.

Will this useful fuel—by aid of which all our great manu-

factures are conducted ; by whose means we are enabled to travel long distances in hours instead of days—will this fuel last for ever? Common sense answers “No,” and men of science support this view.

Sir William Armstrong said, in 1863, that he had calculated that if we continued to raise coal at the ordinary rate of increase of two and three-quarter millions of tons every year, the coal supply of Great Britain would cease in 212 years. But the late lamented Professor Jevons (a great authority in economic science) observed at the meeting of the British Association in 1875, “Supposing that in 1861 the produce of coal was eighty-six millions of tons, it would now be, with the rate of increase of two and three-quarter millions per annum (according to Sir W. Armstrong’s calculation), one hundred millions ; but the fact is it is one hundred and twenty-seven millions, so that Sir William’s calculation was less than the truth by eighteen millions.”

Professor Jevons further remarked, in reference to the coal famine of 1875, “The recent coal famine might be taken as the first fringe of the scarcity which must come sooner or later. That arose from increased demand. No doubt the colliers took advantage of high prices to lessen the hours of labour. There could be no doubt, however, that coal would never again be so cheap in this country as it was from 1864 to 1871.”

Since we cannot have more than the whole of anything (although some of us no doubt would like to do so), it is clear that at some time—probably at no very distant date, if we go on using up our stock of coal at the same reckless rate of increase as heretofore—the last shovelful will be used by its fortunate possessor to boil the kettle for his last cup of tea.

Now, this would be a very melancholy outlook for us if it were likely to occur in our own time. As to those who may

come after us—well, I am afraid our natural selfishness will limit our sympathies to the present generation or so, leaving the future to look to itself.

But as to the future? Is there no gleam of hope for our successors? Are they to suffer for our ruthless and extravagant use of coal—more especially during the present century? Nay, I think not, but venture to hope that Science, which has been the cause of our consuming so many thousands of millions of tons of coal, will come to their aid by lighting their streets, their factories, and their homes by electricity, instead of with coal-gas; by propelling their railway trains and ships by means of the electric current instead of steam, and by carrying out many large and important industries with the aid of the same invisible, but most potent agent, instead of coal. If these anticipations be realised—and I believe we are on the eve of such a transition—the duration of our coal will be greatly extended, probably for some centuries to come, and then—well I think we *may* draw the line here!

II.

What Coal Contains. Origin of Gas Illumination.

The details of a chemical analysis of coal might not prove very interesting to the non-scientific reader; neither would they promote the object of this little work, which we desire to be of an unscientific character, so as to be understood by the general reader. We will therefore devote our attention more especially to the chief products of coal which are obtained by what is termed *destructive distillation* during the process of gas-making for illuminating purposes.

If instead of burning coal in an ordinary grate we put it into a large iron retort, having a furnace fire beneath, as they do at the gasworks, and distil over and collect in proper

receivers everything which the coal contains but its coke (which remains in the retort), we shall obtain a great number of very interesting and valuable products, and these, when treated by certain chemical processes, will give us most astonishing results.

When coal is heated in a retort steam and air first pass over, and as the retort becomes hotter volatile or gaseous matters become separated from the heated mass, and tar and water, impregnated with carbonate of ammonia, &c., distil over in considerable quantity; as also hydrogen gas, carburetted hydrogen, and other gaseous matters, which become liberated as the retort becomes red hot.

We have said that water containing carbonate of ammonia distils over from the retorts during the process of gas-making. Now, there is nothing in the appearance of a lump of coal to lead us to expect it to contain a pungent substance such as ammonia. Who would expect to find the chief ingredient of *sal volatile* in a lump of coal? Yet, however absurd this might appear, he would not seek in vain. Neither should we expect to obtain from our "black diamond" a bright, clear spirit, resembling ether in appearance; yet *benzole* or *benzene* is obtained from the products of coal. Again, who would have the temerity to search in coal for a substance having the smell of oil of bitter almonds, and which commonly does duty for that agreeable but poisonous flavouring amongst our blancmanges and other sweetmeats under the title of "almond flavouring?" Nevertheless, gentle reader, these and many other useful substances are obtained from coal, as will be explained hereafter.

It will be readily conceded that one of the most useful purposes to which coal has been subjected by the ingenuity of man, is the utilising its gaseous products for illumination. The

first practical attempt at gas-lighting was made by Mr. William Murdock, engineer to Messrs. Bolton and Watt, in 1792, who applied coal-gas for lighting his house and offices at Redruth, in Cornwall. He generated the gas in an iron retort, from which it passed into a gasometer, being thence distributed by pipes to the various parts of the building, and was burned at very small apertures, which could be opened and closed at will. He also constructed portable gas-holders, made of tin-plate, which could be carried about to be burned where required.

From 1792 to 1802, Mr. Murdock made many experiments in gas-lighting, and upon the occasion of the National Illumination at the Peace of Amiens on May 10th in the latter year he lighted up a portion of Bolton and Watt's factory at Soho, near Birmingham, with a public display of gas-lights. This was doubtless the first practical attempt at gas-lighting upon a tolerably large scale. Though tardily, yet surely, Murdock's system of gas illumination received the attention its importance deserved, but it was not until 1804-5 that it was fully recognised and adopted upon an extensive and systematic scale, under his own superintendence, at the cotton mills of Messrs. Phillips and Lee, in Manchester, where a gas apparatus was fitted up capable of giving lights throughout the building equal to about 3,000 candles.

Two years after, namely, in August, 1807, gas-lighting was first introduced into London, near the old House of Lords. From this period its adoption was promoted with increased zeal, many public companies in London and the provinces were established, and by the year 1822 its adoption throughout the whole country became almost general. We now know how universal has been the application of coal-gas for lighting purposes since its first introduction, but where is the monument to

William Murdock, to whose exertions the whole civilised world is indebted for this splendid system of artificial illumination? England is not often so ungrateful to her benefactors as in the case of the originator of gas-light!

Passing from our slight reference to the origin of gas-lighting, it may be well to consider briefly the principles upon which *combustion* is carried on in the air, before treating of the *destructive distillation* of coal, or conversion of coal into gas. We must understand that during the process of burning, as we call it, nothing is absolutely lost. We may destroy the form of coal or wood, for example, by burning them, and if we do this in an ordinary grate, we find nothing left behind but a few ashes—no coke, no charcoal, no tar, but yet there is not a single atom of the original material really *lost*. To some of us it may sound strange to be told that after we have burned a sack of coal, and found nothing but a few ashes left in the grate, and a little soot up the chimney, that nothing has really been lost, and that as a matter of fact if all the products which existed in the coal before it was burned were collected and weighed, we should find that there was a positive *increase* in weight. We will endeavour to explain the cause of this in a few words.

Neither coal nor wood can burn—that is, undergo combustion—nor can animals exist without *oxygen gas*; and the air we breathe is composed of this gas, diluted with another gas called *nitrogen*. Now, when a piece of wood or coal—both of which contain a large quantity of a solid substance called *carbon*—is ignited, this carbon unites with the oxygen of the air, forming *carbonic acid gas*. This compound gas passes into the air and becomes absorbed by the leaves of plants, and also by the moist earth. The leaves, being the lungs of a plant, absorb or inhale carbonic acid, when it undergoes in their system a process of digestion, as it were: the oxygen, being set free, again passes

into the air, while the carbon is retained by the plant, and thus adds to the solidity of its structure.

The oxygen disengaged from the leaves of plants supplies the air with our lung food, which we, in common with all other animals (don't be offended at being called an animal, gentle reader), inhale; and this gas, uniting with surplus carbon in our lungs, is again expelled, at every breath, in the form of carbonic acid. We thus see that plants give us oxygen to breathe, while we in return supply them with carbonic acid, which keeps us on good terms with each other by a system of chemical reciprocity, or fair trade in gases!

It must be evident, then, that if carbon, in burning, unites with oxygen, it must weigh heavier than before its combination with that gas, for even gases possess weight. In order that we may be more fully understood, a few words upon the *atomic* theory of Dr. Dalton may not be unacceptable. An *atom* is a substance in so small a state of existence that it cannot be divided or separated. Now atoms unite, or combine with each other, in *definite proportions*, whether it be *atom to atom*, or a number of atoms (a multiple of one atom) united to form compound atoms. For example, water is composed of one atom or part *by weight* of *hydrogen*, and eight atoms or parts by weight of *oxygen*; therefore, if one pound of hydrogen be combined with eight pounds of oxygen, nine pounds of water will be formed. Again, if six parts of carbon are combined with sixteen parts of oxygen, the result will be twenty-two parts of carbonic acid.

We therefore find that when coal or wood is burned (and they cannot burn without oxygen) the carbon, which forms the greater part of their substance, in uniting with oxygen of the air, becomes converted into carbonic acid gas, which is sixteen parts in twenty-two heavier than the original carbon itself.

Besides this source of increase in weight, when coal is burned its hydrogen combines with oxygen of the air, forming water, so here we have an addition of eight parts of oxygen to every one part of hydrogen which the coal yields during the process of combustion. We thus see that in burning, the products of coal acquire considerable increase of weight.

Animals cannot breathe carbonic acid, neither can wood or coal burn in it. To prove this, in a very simple way, a small piece of wax taper or candle-end is secured to a piece of wire. If we now light the taper and lower it into a clean and dry wide-mouthed bottle, in a few moments the candle will go out; and if it be relighted and again passed into the bottle, it will become extinguished instantly. Now this little experiment shows that the candle-flame used up all the oxygen contained in the small quantity of air in the bottle, and, uniting with the *distilled carbon* of the flame, formed carbonic acid—a gas fatal to combustion and animal life. It is this gas which forms the froth of ginger-beer, soda-water, bottled beer, and champagne; and the refreshing qualities of water are due to a small amount of this gas (as also a little oxygen) which it dissolves or absorbs from the air. When water is boiled and allowed to cool it has a mawkish, *flat* taste, owing to these gases being expelled by the process of boiling.

We may thus see that our jump from a lump of coal to talk about gases is not out of place after all, for coal, being chiefly composed of carbon (to the extent of about three-fourths of its weight), the moment it becomes ignited in the air almost its entire substance is converted into the invisible and deadly gas (carbonic acid) called by miners “fixed air” or “choke-damp.” If we sit in a badly-ventilated room, with the door closed and a gasalier burning, we soon feel oppressed and uncomfortable—not from heat, but from a sense of suffocation or

“stifling.” The causes of our disagreeable sensations are, first, the gaslights and ourselves have used up most of the oxygen in the room ; and, second, have replaced it by carbonic acid—a chemical compound of oxygen and soot !

Is soot, then, carbon ? you may ask. Certainly it is, and if we knew how to burn our coal—which we do not—instead of having our chimneys and the air choked with soot we should burn it all, and by doing so use less coal and have no dirty pea-soup fogs to annoy us in dull and damp November, for the odious London fog is largely indebted to soot or wasted coal for its nastiness.

Carbon assumes many forms. Besides being the chief constituent of the various kinds of coal and jet (from which very pleasing ornaments are made), animals and plants are largely built up with it. Plumbago, or black-lead, is a form of carbon, and when this is made into rods or “points,” as they are commonly called, it is used in electric lamps for producing the electric light. The interior of gas retorts which have been used for a long time become coated or incrustated with a thick layer of *fixed*—that is, not volatile—carbon, which, when removed from the retorts, is largely used for electric lamps and for Bunsen’s zinc and carbon batteries. But of all the varied forms of carbon there is one of which its owner may be justly proud—especially if it be a fine specimen—we mean the diamond—*which is pure carbon*. Even this beautiful gem, which, besides being the most costly, is the hardest substance known, may be converted into ginger-beer froth, so to speak, in a few moments. If a diamond be suspended by a platinum wire, then made red-hot (which will not harm it) and now passed into a bottle filled with oxygen gas, it will burn with intense brilliancy, most charming to behold, but, alas ! the grand display will be at the sacrifice of its own existence, for it will be a diamond no more.

A bottle filled with carbonic acid will alone remain as a useless monument to its departed worth. We should not like to see the Koh-i-Noor treated thus! There is a marked contrast between a cake of "black-lead" (graphite) and a brilliant of the first water; yet, chemically speaking, there is but a trifling difference. With all respect for its chemical *status*, however, we shall not look upon "black-lead" in the presence of his crystallised prototype.

Wood charcoal is another familiar form of carbon, and is the coke of wood. It remains in the retorts after the wood from which it is produced has been subjected to the process of destructive distillation for the purpose of collecting its volatile constituents—wood naphtha, creosote, pyroligneous acid (acetic acid, or wood-vinegar), and pitch.

Another important *element* (that is, a simple substance from which nothing else can be extracted by any known means) in coal is *hydrogen*. It is this gas, in combination with carbon in a gaseous state, that constitutes the ordinary coal-gas used for lighting purposes. Hydrogen is a highly inflammable gas, and when pure it burns with a pale bluish flame, possessing but little illuminating power by itself, but when mixed with carbon it yields a bright white light. When pure hydrogen, or *carburetted hydrogen* (coal-gas), is mixed with atmospheric air or oxygen, in certain proportions, if a flame be brought near the mixture, a violent explosion takes place, water being formed by the union of the two gases.

We have frequently heard, with the deepest regret, of the terrible explosions of *fire-damp*, as the miners call the gas which escapes from the fissures in the coal seams, and have been appalled at the fearful destruction of human life which has resulted from each explosion. To prevent such disasters, the gifted philosopher, Sir Humphrey Davy, devoted his noble mind,

some fifty or sixty years ago, until he finally succeeded in constructing a "safety lamp" which could be burned in a coal mine without igniting one of the miner's worst foes—hydrogen. The Davy lamp, if properly used, and not abused, as good things too often are, was not an accidental discovery or "happy thought," but was the result of careful research, pursued by one of the brightest geniuses and most original of thinkers ever

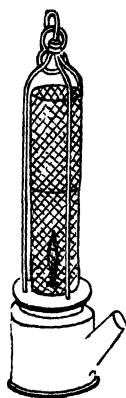


Fig. 1.

known to fame. Davy found that when a piece of wire gauze was held close over a gas-burner, and a light applied above the gauze, the gas ignited; but when the gauze was removed to a short distance from the burner, the flame *did not* pass through the wire gauze. It was this grand fact which led up to the construction of the Davy safety lamp (Fig. 1). Davy found that the metallic gauze conducted the heat away so quickly that the gas *could not burn*. If, therefore, an oil-lamp or candle be enclosed in a tube or case of wire-gauze (as in the ordinary Davy lamp) it will burn and give light, because *the air can pass inward*, through the meshes of the gauze, but *the flame cannot pass outward* through it: consequently it cannot ignite any coal-gas that may be present in the mine.

Hydrogen is the lightest substance known, and for this reason it is employed for inflating balloons. Pure hydrogen, however, is seldom used for this purpose, because coal-gas (carburetted hydrogen) is more readily obtained.

III.

Manufacture of Coal-Gas.

Pit coal is divided into several classes, the most important of which are :—1. *Lignite*, or *brown coal* ; 2. *Bituminous coal*, or *caking coal* ; 3. *Anthracite*, or *stone coal* ; 4. *Steam coal*. Of these varieties the second, or bituminous coal, is the most valuable for the production of gas. When heated, it first splinters, and the fragments then fuse together into a bright and glistening mass, resembling tar, which sets hard again on cooling. Since it is this species from which we select our lump of coal for illustration, let us consider, briefly, how it is used in the manufacture of ordinary gas for illuminating our homes and our streets.

A large furnace, *a*, is constructed of brickwork (Fig. 2), in which a series of cast-iron retorts (usually five in a group) are fixed, each having an iron tube or *exit pipe* connected to it, to carry off the volatile or gaseous matters which are liberated by the heat of the furnace. These tubes are connected to a horizontal cylinder, *b*, termed the *hydraulic main*, in which the crude gas deposits a portion of its tar and ammoniacal liquor.

The gas then passes through the pipe, *c*, into the tar pit, *d*, and from thence into the condensing pipes, *e*, after which it passes through an apparatus, or tower, filled with coke, not shown in the engraving, called a *scrubber*, where it becomes deprived of further impurities. Having been thus far purified by what may be called *mechanical* means, the gas next undergoes a final purification of a *chemical* nature, which deprives it of carbonic acid, sulphuretted hydrogen, &c. This consists in allowing the gas to pass through what is termed the *lime purifier*, *f*, which contains either dry slaked lime, or *milk of*

lime (lime mixed with water), in which it is agitated by the vertical stirrer, or "agitator," *g*. From this the gas enters by

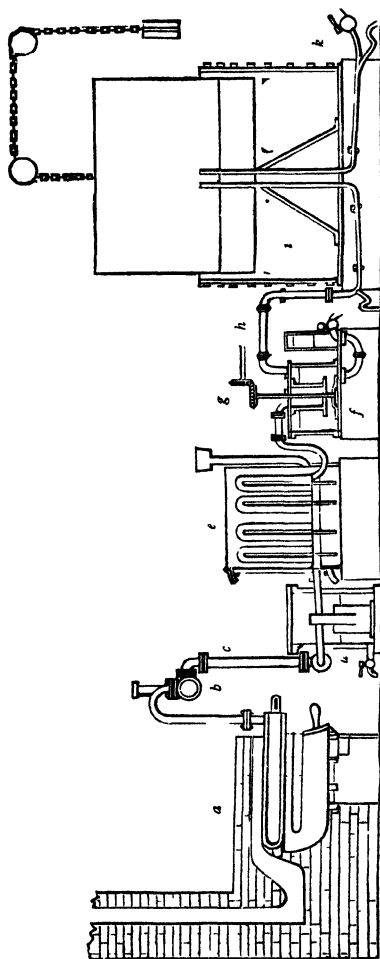


Fig. 2

the pipe, *h*, into the gas-holder, *i*, and is supplied to the distribution pipes by means of the main pipe, *k*.

A furnace door, with exit pipe, *a*, is shown in Fig. 3. The handle or lever, *b*, being turned round toward the left hand,

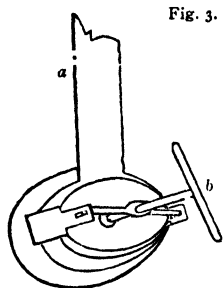


Fig. 3. enables the workman to remove the door with perfect ease.

The rationale of the process of gas-making may be thus briefly described : Soon after the retorts are charged with coal (the furnace fires being lighted) steam and air at first pass over, followed, as the retorts become hotter, by gas, tar, and water, containing carbonate of ammonia and other volatile matters. When the retorts become red-hot the liberation of gas is at its highest point, and it continues to pass over freely, accompanied by tar and ammoniacal liquor. After a while, the distillation diminishes, until finally it ceases altogether. In practice, the coal is placed in the retorts while they are red-hot, by which a large proportion of the tar becomes converted into good illuminating gas, instead of being distilled over as a comparatively waste product. When all the volatile matters have been evolved from the coal, coke alone remains in the retorts, and this is afterwards removed and quenched with water, and is used as fuel in further operations, and the surplus sold to the public.

When the distilled vapours leave the retorts they first enter the hydraulic main, where a portion of the tar and ammoniacal liquor becomes deposited ; and when these fluids reach a certain height in the receiver they flow over into the down pipe, *c*, and are received in the tar pit, *d*. The gas now enters the *condenser*, which is a large water-tight tank, generally made of wrought-iron plates rivetted together. The tank is open at the top, and in its centre a series of curved pipes are fixed, through which the gas passes up and down, while the condensed liquids

descend into a chamber below, and flow over into the tar pit. The condenser is kept supplied with cold water, which, by cooling the hot vapours that issue from the retorts, enables them to condense into the liquid form. By this means, also, the gas becomes refrigerated before it enters the lime purifier, *f*.

The *lime purifier* is a cylindrical iron vessel, with an air-tight cover; in this another cylinder is fixed, through which passes a shaft or spindle, attached to an *agitator*. The shaft is set in motion by steam power, as indicated by the two bevel wheels above the cylinder. The outer cylinder is filled with *milk of lime** (made by mixing slaked lime with water), and this is kept well stirred by the agitator. The gas which issues from the condenser pipes passes through the milk of lime, which keeps back most of the carbonic acid and sulphide of hydrogen with which it is associated.

In order to free the gas as far as possible from the last traces of ammonia and sulphuretted hydrogen derived from the sulphur which more or less exists in coal, it is passed through the scrubbers before referred to. These are sometimes wrought iron towers, filled with coke. On the top of each tower is a cistern of water, which is allowed to fall in the form of a fine spray, so as to keep the coke well moistened. The large surface which the wet coke presents deprives the gas of most of its remaining impurities. The gas is then introduced, by means of an exhausting apparatus, into the water-cistern at the base of the gas-holder, and from thence it rises into the gas-holder itself.

The gas-holder, or "gasometer," as it is sometimes erroneously called, consists of two essential parts—the water cistern and the floating chamber or gas-holder proper, which collects

* Dry slaked lime is now commonly used for this purpose.

or stores the purified gas ready for distribution for lighting purposes. When the cylinder is empty, it sinks by its own weight into the lower cistern, and becomes filled with water. The purified gas, passing through this water, rises up into the cylinder, and by displacing the water causes it to rise. To facilitate this, and also to regulate the pressure of the gas in the distribution pipes, a series of counterweights, suspended by chains running over pulleys, are attached to the cylinder, at equal distances round its circumference.

When the gas-holder sinks into the water cistern (during the consumption of its gas) it loses its weight in proportion to the weight of water it displaces, and the pressure upon the gas is therefore diminished as it sinks lower into the water. To overcome this loss of pressure the weight of chains which support the gas-holder is so regulated as to counteract the unequal pressure which would otherwise arise and influence, prejudicially, the uniformity of the gas distribution proceeding from the gasometer. At its base is the *main pipe, k*, with stopcock attached, through which the gas passes from the cylinder to the distribution pipes in the various public thoroughfares.

The amount of gas obtained from a ton of good pit coal, distilled at the London gasworks, is about 10,000 or 12,000 cubic feet; and according to Dr. Letheby, one ton of gas coal, as distilled in London, gives nine to ten gallons of tar; by a different system the same quantity of coal distilled in the provinces yields about fifteen gallons of tar.

One thousand gallons of tar yield:—

Ammoniacal liquor (about)	-	24	gallons
Crude light oils	„ -	12	„
Second, or heavier oils (about)	-	12	„
Creosote oils (heavy oils)	„ -	288	„
Pitch	- - - „ -	3	tons 6 cwt.

IV.

The Volatile Products of Coal.

We will now turn our attention to the volatile products which our Lump of Coal is capable of yielding after its gas has been generated and purified to give us artificial light, and its coke has been employed to heat the gas retorts for the production of more gas, or to heat our steam boilers and furnace fires. Leaving the ammoniacal, or "gas liquor," for a while, let us consider what we can obtain from the coal-tar when subjected to distillation from a suitable still.

Distillation of Tar.—When coal is subjected to *destructive distillation*, three great commercial products are obtained—namely, *gas*, *tar*, and *coke*. The gas being used for illumination and the coke for fuel, let us see to what purposes tar can be applied besides painting our barges and wooden palings, and we shall find that this black, sticky, and strong-smelling substance is a compound capable of yielding a very surprising number of interesting products, to which learned chemists have applied very pretty, and in some instances almost ladylike names, as aniline, anthracene, naphthaline, &c.

The distillation of tar is a very extensive manufacturing industry, and is carried on chiefly in the outskirts of London and other large towns. The tar, as it comes from the gasworks, is placed in large tanks, where it is allowed to stand for a while to enable any ammoniacal liquor which may be mingled with it to rise to the surface, and this is drawn off to be treated chemically for the manufacture of ammonia. The tar is pumped from the bottom of the tanks into large stills, and is then subjected to a moderate amount of heat. At first, water containing sulphide of ammonium (a compound of sulphur and ammonia) and some of the more volatile products pass over into the receiver, and these first products are set aside as

ammoniacal liquor and first light oils (crude coal naphtha). Some time after, these cease to flow, when the heat is increased and a series of heavier products, called *medium oils*, pass over and are collected into another receiver, and finally what are called *heavy oils*; and when these last products cease to flow the operation is complete, and nothing but pitch remains behind in the still.

During the process of distillation a hydrometer is applied from time to time to the distilled matters in the receiver, and by this means the various stages of the process are carefully watched. The hydrometer is an instrument which floats in the liquor to be tested, and this rises or sinks according to the density of the fluid. Water, being taken as the standard, stands at 1000 on the instrument, whereas in the lighter or heavier products the hydrometer will indicate so many degrees above or below these figures.

In separating the various substances contained in the products of the above distillation, certain chemical treatment is applied, and the thermometer is greatly depended upon as a guide in separating the lighter products from those of greater density. For example, at a temperature of 200° Fahr., or twelve degrees below the boiling point of water (212° Fahrenheit), a very light spirit (*benzole*, or *benzene*) is obtained, which, when purified, has a *specific gravity* or density of .850, or 150 grains lighter than water. This is not, however, *pure benzole*, to obtain which a delicate form of rectification is necessary. The commercial benzole is first well agitated with concentrated oil of vitriol (sulphuric acid), which causes it to assume a dark brown colour. It is then set aside to settle, after which the spirit is rectified by redistillation at a temperature below 195° Fahr. The *distillate*, as it is termed, is next reduced to a temperature below the freezing point of water (32° Fahr.),

when it crystallises. The crystals are then placed upon a funnel (also refrigerated to the same low temperature) and allowed to drain; they are afterwards pressed between folds of filtering paper, and then placed in a closed vessel and allowed to thaw, as we may say, at the ordinary temperature of the atmosphere. This liquid is again distilled at a temperature below 190° Fahr., when it becomes nearly pure. To obtain absolutely pure benzene, however, the system of freezing and redistillation has to be repeated several times, the last rectification being at a heat below 185° Fahr. It will thus be seen what great skill and care have been bestowed upon the purification of this, the most important substance obtained from coal tar.

Benzene, when pure, is an exceedingly light spirit, very volatile at all temperatures, and boils at about 176° Fahr. It becomes solid at the freezing point of water, and if allowed to attain this temperature gradually, it crystallises in delicate fern-like forms. It is exceedingly inflammable, and its vapour will ignite, especially in a warm room, when an uncorked bottle containing it is many inches apart from a lamp or other flame. If a few drops of benzene be poured upon the back of the hand and blown upon they vanish by rapid evaporation, almost instantaneously, producing a very cold sensation. The vapour of benzene, when mixed with air, is also highly explosive; therefore, since it possesses such very dangerous characteristics, it must be used with great caution, and not on any account be employed in an apartment in which there is either a fire or a lamp burning. We are led to these remarks because, under various names, as *benzine collas*, for example, it is commonly sold for cleaning gloves, removing grease-spots, &c. It is a painful fact that Mr. C. B. Mansfield, the discoverer of benzole (or benzene), lost his life by being severely burned, while making

experiments with this useful but dangerous substance. The more important and interesting uses to which benzole is applied will be considered hereafter.

After the benzole is distilled over from the crude coal naphtha the remaining product is treated with strong sulphuric acid, which carbonises or chars the chief impurities, which deposit in the form of a heavy black acid mass resembling tar. The clear oil is then separated and treated with caustic soda, after which it is again distilled, when a lighter oil is obtained, which is used as a substitute for turpentine for dissolving India rubber, and also for burning in the lamps used by costermongers. When this naphtha has been separated, a good burning oil is obtained by increasing the heat of the still up to a certain temperature.

When all these lighter volatile oils have been distilled over, and the heat of the still again raised, the last product which passes over consists of a heavy oil, from which, on cooling, a peculiar crystalline substance is obtained, called *naphthalin*. This substance separates from the body of the oil, and is afterwards collected, drained from the oil, and redistilled several times, when it ultimately becomes beautifully white and crystalline. It has a powerful odour and is highly inflammable, burning with a red flame, with abundance of smoke.

When cannel coal or boghead coal is heated in a retort at a much lower temperature than is required for making gas for lighting purposes, but very little uncondensable gas is formed, the volatile matters passing over chiefly in vapour, which condenses into the liquid form. In this way Mr. Young produced his well-known *paraffine oil*. Instead of employing retorts, such as are employed at the gasworks, perpendicular tubes or retorts, about eleven feet high, are used, and these are built in sets of four, which pass right through the furnace. The

coal is put into the upper end of each tube, which is furnished with a *hopper*, and is opened or closed by a valve. The lower end of each retort dips into a shallow pool of water. The exhausted coal, or that which has become deprived of its constituents by the heat of the furnace, falls to the bottom of the retorts and is raked away by the workmen, while a fresh supply is constantly introduced into the hoppers above, and thus the operation goes on both night and day without interruption. The volatile matters are conveyed by pipes to the *condensers*, which consist of a series of curved tubes exposed to the air.

The *crude oil*, which is of a dark brown colour and of a thickish consistence, is next distilled *to dryness* in iron stills, by which it becomes freed from much of its carbon, which remains in the retort as coke. The distilled oil is then well agitated with strong oil of vitriol, and after this and the impurities combined with it have subsided, the oil is again subjected to distillation, when *paraffine naphtha* at first comes over, and when this ceases to be produced, the next product that comes from the still is the well-known and valuable oil known as *Young's Paraffine Oil*. It is a matter of great care on the part of the manufacturers to avoid *any* admixture of naphtha with the oil, owing to its inflammable nature, and it is to this caution that we are indebted for the comparatively few accidents which occur from the employment of this, the best of all lamp oils.

The next commercial product which is obtained after all the paraffine oil has passed over is a heavier liquid called *machinery oil*, from its being much used in lubricating, or greasing, various parts of machinery. When this oil and the last products of the distillation are subjected to a very low temperature, a white, solid, and semi-transparent substance is

obtained, which is called *paraffine*, and is much used for making candles.

If we look upon one of those beautifully delicate paraffine candles—so like the elegant spermaceti in appearance—we may well wonder that such a substance can be obtained from a lump of coal.

Anthracene.—It had long been known amongst chemists that a crystalline substance called *paranaphthalin*, or *anthracene*, could be obtained from the heavy oils of coal tar; but until a comparatively recent date it was known more as a scientific fact than as possessing any practical value. This remarkable substance is now, however, found to be of the utmost importance in the production of *alizarin*, to which we shall have to refer hereafter.

By a process known in chemistry as *fractional distillation*, or *fractionation*,* many different substances are obtained from the coal oils. The lighter, or more volatile products, which distil over at the lowest heat, contain less carbon in their composition than those which require a higher temperature to convert them into vapour. When submitting the oily products of coal tar to fractional distillation, conducted with profound care, chemists have from time to time discovered substances not previously known to science, which have led to some of the most remarkable results which have ever been obtained by the skill and perseverance of man.

Ammonia from Coal.—The word *ammonia* is derived from a Greek word signifying *sand*, and is the name of a sandy district in the Lybian desert where, near the Temple of Jupiter Ammon, the Egyptians formerly obtained a salt of ammonia, called *sal-ammoniac* (hydrochlorate of ammonia), by burning

* This process consists in separating substances which distil over at different temperatures, and collecting them in separate receivers

the dung of camels and other animals which fed upon saline plants of the desert. The soot produced from the burnt camels' dung was afterwards subjected to heat in kilns, and the salt obtained by sublimation. It was at one time largely imported into Europe as an article of commerce.

Ammonia exists in the juices of certain plants, in the blood of animals, and is disengaged during the decomposition of animal and vegetable substances; it also exists in the air, but more especially in the neighbourhood of large manufacturing towns, where the consumption of coal is considerable.

We have frequently referred to the ammoniacal liquor which passes over from the retorts during the process of distilling coal for gas-making. Let us now see to what useful purposes we can apply it by skilful chemical processes, so as to extract from the crude "gas-liquor" its most valuable constituent—ammonia. It is necessary here to state that gas-liquor, besides containing a large quantity of *carbonate of ammonia*, also contains other matters of little or no practical value, from which this salt must be separated by careful treatment.

The ammoniacal liquor, after its removal from the tar pit, is either treated with sulphuric acid, which converts its carbonate of ammonia into *sulphate of ammonia*, or with hydrochloric acid, which forms it into *hydrochlorate of ammonia*, or sal ammoniac.

Hydrochlorate of Ammonia.—The gas-liquor is first placed in large covered wooden vats, lined with lead, and capable of holding at least from ten to twenty thousand gallons; and these are sometimes sunk in the ground for the greater convenience of manipulating them. The acid (hydrochloric acid) is introduced by lifting the "carboys" in which it is contained by means of pulleys; and in this way the carboys are emptied, one by one, into the vat. While the acid is being poured in, the mixture is kept constantly stirred by "agitators" worked by

steam power, so that the acid may be well diffused through the whole bulk of the liquor, which is tested from time to time until the decomposition is complete, and all the ammonia perfectly saturated—a slight trace only of acid being allowed. To carry off the noxious and poisonous fumes which are generated by the chemical action thus set up, an *exit-tube* is connected to the upper part of the vat or tank, through which the fumes pass either into the main chimney of the steam boiler, or through the boiler fire before they enter the chimney.

The amount of hydrochloric acid required to neutralise the carbonate of ammonia in the vat depends upon the percentage of ammonia in the liquor, which varies according to the nature and quality of the coal employed. From one and a half to two pounds of acid are usually required to saturate each gallon of gas-liquor.

Instead of treating the gas-liquor with acid in the crude condition in which it occurs when removed from the tar pits, it is commonly the practice to first subject the liquor to re-distillation, by which it becomes freed from tar and other volatile impurities. For this purpose the gas-liquor is placed in large wrought-iron boilers, and the distillation is conducted with care, so as to keep back, as far as possible, certain empyreumatic matters with which it is impregnated.

When the ammoniacal liquor has been *neutralised* with acid, it is pumped or run off into vessels called "evaporators." These are large cast-iron pans or vats, capable of holding several thousand gallons of liquor; these pans are set in brick-work, with furnace fires beneath. During the progress of evaporation, a tarry scum forms upon the surface of the liquor, which the workmen remove by skimming. When the evaporation has been carried sufficiently far, a *pellicle*, or thin film, forms upon the surface, when the now concentrated liquor is allowed to rest

for a short time, after which it is pumped into "crystallisers," which are large shallow wooden vessels, about eight feet wide by three feet deep. In a short time crystals begin to form, as the solution cools, and in order to prevent the crystals from becoming large, which would retard the subsequent treatment of them, it is usual to stir the liquor from time to time. The process of crystallisation occupies about a week, more or less, according to the size of the crystallising vessels. When the crystallisation is complete, the "mother liquor" (that is, the liquid which lies over the surface of the crystals) is pumped out, and again placed in the evaporating pans to be concentrated by heat as before. The crystals are then drained to free them from the mother liquor which attaches to them, after which they are dried upon iron plates gently heated by the flue of a small furnace—the heat from which is sufficient to expel the water, but not high enough to evaporate the ammonia salt.

The dried salt is next purified by *sublimation*, in cast-iron "pots," lined with clay, and heated by furnace fires placed beneath each pot. Fig. 4 represents the subliming pots, *a a*.

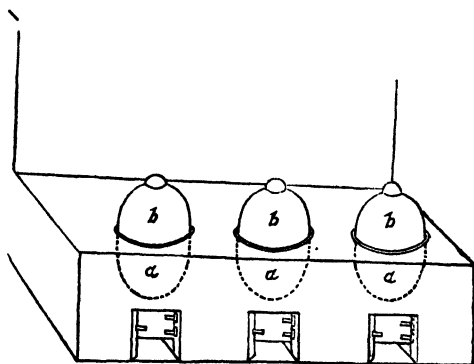


Fig. 4.

covered by "heads," or domes, *b b*, which are generally made

from lead or cast-iron, and, being very massive, they are raised or lowered by means of pulleys and chains attached to a stout beam overhead. The dried salt, after being placed in the subliming pots, is well pressed down, and the heads then placed over, which are secured by clamps to the flange of each pot. Fig. 5 shows the form of the subliming pot in outline.

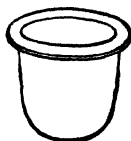


Fig. 5.

The regulation of the heat is of great importance in subliming the crude ammonia salt, for if the temperature be too high certain volatile oily matters with which the salt is contaminated will pass over into the domes and impair the purity of the product; while, on the other hand, if the heat be too low the sublimed salt (*sal ammoniac*) will be spongy and soft. The workmen employed in the subliming house generally determine the proper heat of the sublimers by letting a few drops of water fall upon the head, when, if the water *boils*, without being jerked off suddenly, the desired temperature is attained, and the fires are kept up to a moderate heat, so that no increase of temperature may arise. The process of sublimation takes about a week; but in order to ascertain how the operation progresses, the fires are occasionally slackened and the heads raised, to enable the contents to be examined. Care is always taken, also, to check the process of sublimation before the entire quantity of the ammoniacal salt has been expelled from the pots, lest the volatile impurities should also pass over.

When the sublimation is complete, the furnace fires are drawn or allowed to die out, and the heads allowed to cool, after which they are raised, one by one, by the pulley chains, and the cakes of sublimed *sal ammoniac* are then removed, when they assume the bell-shaped form of the interior of the domes, and are usually about three or four inches in thickness.

The size of each sublimed mass varies according to the dimensions of the apparatus employed, and ranges from about fifty pounds to one thousand pounds in weight. After being removed from the domes, the cakes, or *bells*, of sal ammoniac are transferred to the packing-house, where they are well scraped all over to remove any traces of metal derived from the interior of the head. They are then broken up into lumps and packed in clean casks for sale.

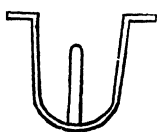


Fig. 6.

The unsublimed portion remaining in the pots generally assumes a conical form, standing erect, and this is called by the workmen "the yolk." Fig. 6 is a section of a subliming pot with the unsublimed mass standing in the centre.

Sal ammoniac may also be produced by treating the gas liquor, after redistillation, with powdered gypsum (native sulphate of lime), which gives up its sulphuric acid to the ammonia, forming sulphate of ammonia, while chalk (carbonate of lime) remains. In carrying out this process the ammoniacal liquor is placed in a series of wooden filters, each being supplied with a layer of gypsum previously crushed into a coarse powder. The filters are placed over one another, with a cistern or tank beneath to receive the decomposed liquor. A leaden pipe, furnished with a stopcock, conveys the liquor to the receiving tank. The liquor is pumped back into each filter several times, so that the decomposition may be as complete as possible. The bottom filter of each series is supplied with fresh gypsum when fresh charges of liquor are given to the filters, and when the draining of the liquor is complete a small quantity of water is poured into the top filter, which, passing through the lower ones, washes out what little ammoniacal liquor remains in the mixture of chalk and unchanged gypsum at the bottom of the filters.

The liquor which results from the above treatment contains, besides sulphate of ammonia, more or less *free* ammonia, and also carbonate of ammonia; and, in order to neutralise these, sulphuric acid is added, gradually, until all the ammonia is converted into *sulphate*. The liquor is next evaporated by heat in a leaden vessel, and the oily matters which rise to the surface are removed by skimming. When the liquor attains a certain degree of concentration, common salt is added to it in proper proportions to convert the sulphate into *hydrochlorate of ammonia*, as described further on.

Sulphate of ammonia is prepared from the crude gas-liquor, much in the same way as the hydrochlorate. Sulphuric acid is first diluted with water, and this is then added to the ammoniacal liquor as before, until all the carbonate of ammonia is converted into *sulphate*, and the solution is afterwards evaporated and crystallised, when a brownish coloured salt (crude sulphate of ammonia) is obtained. To convert this salt into sal-ammoniac it is first dried, and then mixed with an equal weight of common salt (chloride of sodium), after which it is placed in the subliming pots, and subjected to the same treatment as the crude hydrochlorate. During the *double decomposition* which ensues, *sulphate of soda* (a non-sublimable salt) and hydrochlorate of ammonia (a volatile salt) are produced. The latter volatilises and condenses in the form of sal-ammoniac in the domes of the sublimers, while the sulphate of soda remains in the "pots." Sometimes a solution of common salt is added to the solution of crude sulphate of ammonia, when, as before, double decomposition takes place, and the resulting solution is a mixture of hydrochlorate of ammonia and sulphate of soda. To separate these salts, the liquid is evaporated until the sulphate of soda falls to the bottom of the vessel in the form of granular crystals, which are removed from the evaporating

pans or boilers by means of suitable copper implements, and placed aside to drain. When the sulphate of soda has thus been crystallised out, the remaining liquor is a solution of sal-ammoniac, containing a comparatively small amount of sulphate of soda, which is afterwards removed by evaporation and slow crystallisation. The solution of hydrochlorate is next evaporated, crystallised, and dried, and finally sublimed, as before described, to form commercial sal-ammoniac. Sulphate of soda not being a volatile salt, any portions of this which still remain in the hydrochlorate are left in the pots after the process of sublimation is complete.

Commercial sal-ammoniac, prepared by the processes described, is generally sufficiently pure for most purposes in the arts, but when a higher degree of purity is required the salt is re-sublimed from pots made of earthenware, and condensed in glass receivers. It may be produced absolutely (that is *chemically*) pure, by allowing the vapour of liquid ammonia (see page 32) and the fumes of hydrochloric acid to come in contact, when a dense white vapour is formed, which readily sublimates into soft and delicate crystals of pure hydrochlorate of ammonia.

The sal-ammoniac of commerce is a tough, semi-crystalline substance, of a fibrous texture, and is not very easily reduced to powder by a pestle and mortar. It is very readily converted into vapour, and if a small piece be placed on the point of a knife, and heated over a candle-flame, it quickly disappears. When dissolved in water, it reduces the temperature of that liquid considerably. Equal parts of sal-ammoniac and nitre (nitrate of potash) dissolved in water produce a solution *forty degrees colder* than the water itself; for this reason it is sometimes used for making freezing mixtures. Indeed, with a good supply of sal-ammoniac and nitrate of potash, it is quite possible to produce artificial ice in the hottest climate.

Liquid Ammonia.—This highly pungent and volatile substance, which is generally called “ammonia,” is in reality a solution of ammonia in water. Ammonia only exists in the form of gas, but according to Faraday, however, it may be liquefied, under a pressure of 6·5 atmospheres, at a temperature of 50° Fahr., and at the temperature of 60° Fahr. this liquid expands into 1009 times its volume of ammoniacal gas. At 40° below zero, and under the ordinary pressure of the atmosphere, it forms a subtle, colourless liquid, which at 103° below zero freezes into a white, translucent, crystalline substance.

Ammonia (the gas) is composed of four parts by weight of hydrogen and one part by weight of nitrogen. The characteristic pungency of ammonia is not noticeable in either sal-ammoniac or sulphate of ammonia, but if to a solution of either of these ammonia salts a little slaked lime be added the vapour of ammonia is “disengaged” or set free in an instant. This fact leads us to consider how liquid ammonia is manufactured on the large scale for its various uses in the arts and manufactures, and for medicinal purposes.

When recently slaked lime is added to a solution of sulphate of ammonia the ammonia escapes as a gas, and the sulphuric acid with which it was combined unites with the lime, forming *sulphate of lime* – plaster of Paris, in fact. Or when to a solution of hydrochlorate of ammonia slaked lime is added vapour of ammonia is liberated as before, and *chloride of calcium* (calcium being the base of lime) is formed.

To obtain ammonia upon the large scale from crude sulphate or hydrochlorate of ammonia the salt is intimately mixed with an equal weight of recently slaked lime. The mixture is then put into a retort and heat applied, when the vapour of ammonia passes over freely. This vapour not being condensable, except, at very low temperatures, is passed into water, which absorbs it in large quantities.

A form of apparatus for generating and condensing ammonia is represented in Fig. 7. *A* is a cast-iron retort, fixed

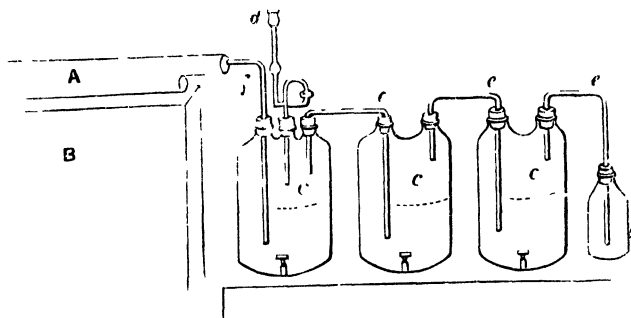


Fig 7.

into a furnace, *B*. The retort is connected by piping to a series of Woulfe's bottles, made of stoneware, *c c c*, and in the centre of the first of these a safety-tube, *d*, is placed. A certain quantity of water is put into each bottle, into which the longer ends of the bent tubes *c c c* are allowed to dip. When the ammonia vapour distils over, it enters by the tube *f* into the water of the first bottle, which absorbs it until saturated, when the vapour continues its course and flows into the water of the next bottle, and so on throughout the whole series, until it finally reaches the last bottle, by which time all the ammonia will have been expelled from the retort. The small bottle *g* is used to indicate whether or not the water in the last bottle is saturated. If the smell of ammonia shows itself at the small bottle, it would indicate that the water in all the Woulfe's bottles is saturated with ammonia; but in practice the number of receivers is so regulated that the last bottle, or that which is farthest from the retort, receives only the last portions of ammoniacal vapour which issue from the latter.

During the process of distillation the receivers are kept cold

by the repeated application of cloths dipped into very cold water. This system of refrigeration is of the utmost importance, for if the ammoniacal vapour were not cooled in this way, instead of being absorbed by the water, a considerable quantity would pass through the tubes and escape into the air, not only causing waste, but rendering approach to the receivers dangerous to the workmen employed in the operation. Sometimes the vapour is passed through a *worm-tub*, or refrigerator, which, in some respects, is the more convenient method.

When distilling ammonia upon a moderate scale, from waste solutions of hydrochlorate of ammonia, we have successfully adopted the following plan; and, although it does not represent an extensive manufacture of liquid ammonia, it may be sufficient to illustrate the principle upon which this article can be produced in a very simple and effectual way. A cast-iron pan, capable of holding, say, about sixty gallons, is set in brick-work

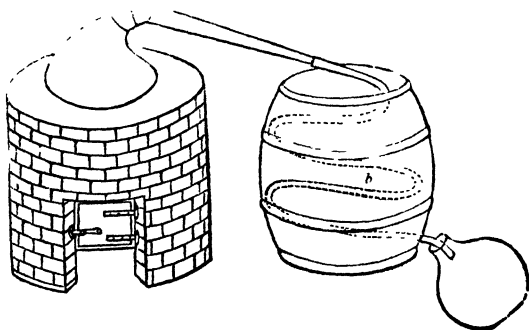


Fig. 8.

(Fig. 8), somewhat like an ordinary "copper," with a fireplace beneath. Above this, a still-head (*a*) made from sheet zinc, carefully put together with solder, is placed, and this is connected to a pewter "worm-pipe" (*b*) enclosed in a wooden tub

filled with cold water. The receivers employed were empty "carboys"—which are large glass bottles capable of holding about twelve gallons, and enclosed in wicker baskets.

When preparing a *charge* for the still the following plan was adopted:—A quantity of fresh lime, previously slaked, was made into a thinnish paste with water, and this well mixed with a strong solution of sal-ammoniac. The mixture was then quickly put into the still-pan, and the *head* placed over it and connected to the worm; at its junction with the pan the head was well luted with linseed meal worked up into a thick paste. The fire was then lighted, and in about half an hour or so the first runnings came over and passed into the receiver. When this was about two-thirds full it was replaced by another carboy, and so on until all the ammonia was distilled over. The last runnings, containing but a slight trace of ammonia, were used as water in the subsequent operations.

In manufacturing ammonia from *crude sulphate of ammonia*, which is contaminated with certain oily and other volatile products, it is usual to put only a small quantity of water in the first receiver (page 33), so that these matters may condense therein, and thus be prevented from entering the second and other receivers in the series.

Pure liquid ammonia is much used in the arts, and also in medicine and pharmacy. It is remarkably pungent and volatile, and cannot be inhaled except when extensively diluted with atmospheric air.

Sesqui-carbonate of Ammonia. This very useful salt of ammonia, which is much used in medicine, and also in the arts, may be prepared by various processes. The following process will give a general idea of the production of the sesqui-carbonate of ammonia ordinarily sold by the retail chemist:—The apparatus usually consists of a set of five retorts (Fig. 9) similar

in form to those used in gasworks, and set into a brickwork furnace, *a*.

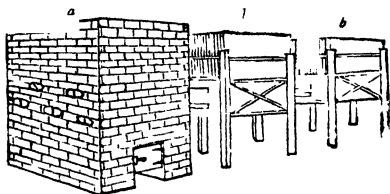


Fig. 9.

At the opposite end of each retort is an iron pipe or tube to carry off the liberated vapours, and a closely-fitting door is attached to the front of each retort.

The receivers, *b b*, are large wooden chambers lined with lead, and placed upon strong wooden or cast-iron pillars. Two leaden pipes, one above another, connect the retorts with the chambers or receivers.

The retorts are *charged* with a mixture of sulphate of ammonia, or sal-ammoniac, as the case may be, and chalk (carbonate of lime), in about the following proportions: Sulphate of ammonia 70 lbs., and chalk 1 cwt.; or sal-ammoniac 57 lbs., and chalk 1 cwt. The chalk is first well washed and dried, and is then intimately mixed with the ammoniacal salt; the mixture is then placed in the retorts, which are heated gradually to cherry redness. The chemical change which takes place in the retorts is simply this: the sulphuric acid, which was combined with the ammonia, unites with the chalk, forming *sulphate of lime*, and the carbonic acid of the lime, being set free, unites with the ammonia vapour to form sesqui-carbonate of ammonia, which, as also a certain portion of free ammonia and water, passes over into the receivers. The sesqui-carbonate condenses in the first receiver, while the ammonia and water pass into the second receiver, which, is furnished with a wooden plug at its base to enable the ammonia liquor to be drawn off. This liquor is afterwards treated with sulphuric acid, which converts it into sulphate of ammonia, to be used in subsequent operations. When sal-ammoniac is used in the above pro-

cess the same result is obtained, but the substance left in the retorts is *chloride of calcium* instead of sulphate of lime.

When the sesqui-carbonate of ammonia is manufactured from the crude or impure sulphate or hydrochlorate of ammonia, the product requires to be re-sublimed, which is done by placing it in iron pots covered with leaden "heads," which are kept cool by a current of air. In order to impart transparency to the sublimed salt, a little water is introduced into each pot. The heat required for subliming the salt is about 200° Fahr., and this is sometimes derived from the flue of the furnace, or by means of a hot-water bath.

Sesqui-carbonate of ammonia, as ordinarily supplied to the druggist, is in the form of white semi-crystalline lumps from an inch and a half to two inches in thickness. It possesses the characteristic pungency of ammonia, and requires to be kept in well-corked jars or stoppered bottles. It is much used in medicine as an antacid and stimulant, and is sometimes employed by bakers to give lightness to their "fancy bread," and also by pastrycooks to give sponginess to their cakes, because it volatilises by the heat of the oven.

Carbonate of Ammonia may also be prepared by mixing equal parts of *dried* and *powdered* sal-ammoniac and carbonate of soda, and heating the mixture gradually in a retort. The carbonate is sublimed from an earthen retort and condensed in a receiver kept *very* cold. It is this salt of ammonia which is used in making up the popular remedy for headache known as "smelling salts"; and its solution is sometimes sold as "spirit of hartshorn."

Carbolic Acid.—This useful deodoriser, and so-called disinfectant, is prepared from crude coal-oil. The commercial article is obtained by agitating a mixture of coal-oil and milk of lime, after which the mixture is set aside for a considerable

time. The liquid portion is then separated from the unaltered oil, and treated with hydrochloric acid, after which it is subjected to slow distillation, only about one-third of the entire quantity being distilled over.

Another process for making carbolic acid is as follows:—The crude oil is first put into a retort, in which a thermometer is inserted, and the product which distils over at a temperature below 400° Fahr. is collected in the receiver and afterwards mixed with a hot solution of caustic potash. After reposing for a while, a semi-crystalline pasty mass is formed, when the clear liquid is poured off, and the mass is well agitated with a small quantity of water until it is dissolved. After a while this solution separates into two portions, the heavier of which is *carbolate of potash*. The lighter liquid is then poured off, and the denser fluid is treated with hydrochloric acid. A solution of *carbolic acid* now rises to the surface, and this, after being decanted from the remainder, is treated with chloride of calcium (a substance having a great affinity for water), which abstracts the water. The carbolic acid is next purified by distillation, the receiver being kept exceedingly cold during the process, when the acid crystallises. The crystals, after being well drained and dried, are placed in well-stoppered bottles to exclude the air.

When pure, carbolic acid occurs in long colourless prismatic crystals, which attract moisture from the air. It is an exceedingly poisonous substance, and should never be left carelessly within the reach of children.

Nitro-benzole.—Since this interesting compound plays a very important part in our little History of Coal, let us now take it into consideration. Mitscherlich, a German chemist of great ability, when experimenting with benzole, in the year 1834, found that strong nitric acid converted the light volatile

spirit into a heavy liquid of an oily consistence, having a powerful odour, resembling oil of bitter almonds. This was afterwards sold to perfumers under the title of *essence of mirbane*.

Nitro-benzole is prepared by dropping strong fuming nitric acid into benzole. Violent chemical action takes place, with generation of heat. After a while the violence of the reaction subsides, when water is added to the liquid. A heavy oily fluid of a yellow-orange colour now separates and falls to the bottom of the vessel. It is afterwards well washed and dried. This substance is much used to impart an artificial flavour of bitter almonds to confectionery. The most important use of nitro-benzole, however, is in the manufacture of *aniline*, to which substance we must now turn our attention.

Aniline. This remarkable substance, which derives its name from *anil*, one of the plants (*Indigofera anil*) which yield the blue colouring matter known as *indigo*, is obtained from that substance by chemical processes. Its production from coal-tar, however, is one of the many marvellous results of scientific research which have so greatly enriched the history of coal during the past half-century. Unverdorben first obtained aniline from the empyreumatic oils [distilled from bones; but subsequently Runge obtained it from coal-tar. There are now many chemical processes for manufacturing aniline, from which we will select one or two of the most simple, and therefore more easily understood.

1. To a mixture of iron filings 2 parts and acetic acid 1 part, an equal volume of nitro-benzole is added, the whole being placed in a glass or stoneware retort, provided with a receiver. Effervescence at once takes place, and when this subsides, gentle heat is applied to keep up the reaction. A clear, white liquid passes into the receiver, which is aniline mixed with

water. To separate the water, the mixture is allowed to repose for some time, when the aniline, being slightly heavier than water, subsides. The water is next poured off, and the aniline carefully bottled.

2. Mix in a retort 4 ounces of iron filings with about 2 ounces of acetic acid, then add about an equal volume of nitro-benzole. Brisk effervescence takes place as before, and the aniline and water pass over and condense in the receiver. To separate the aniline from the water it is recommended to add a little common salt, which, dissolving in the water, makes it more dense than the aniline, which then rises to the surface. Any little water that may be troublesome to separate from the aniline may be removed by putting dry chloride of calcium into the vessel, which will at once absorb it. The aniline is afterwards purified by redistillation.

The Uses of Aniline. We now come to what may fairly be considered, if not the most interesting, certainly the most remarkable part of our subject THE PRODUCTION OF COLOURS FROM COAL. If we look upon a lump of coal, what do we see in it that would suggest the possibility of extracting from it anything possessing *colour*? Its very intense blackness seems to deny the possibility of its taking any part or share in the production of colouring matter of any kind. But that things are not always "what they seem" is amply verified as we go deeper into the history of our Lump of Coal.

It was a Russian chemist, named Zinin, who discovered that nitro-benzole could be converted into aniline; but it remained for other experimentalists to discover the peculiar power which this remarkable substance possesses of producing colour when treated with certain chemical reagents. In 1835 Runge discovered that a solution of aniline, or of its salts, acquired a blue tint when heated with chloride of lime. This was con-

sidered an interesting scientific fact at the time, but it was not followed up by any practical result. Twenty-one years later, however—namely, in 1856 the world was startled by the remarkable discovery of Mr. W. H. Perkins, who found that by dissolving aniline in sulphuric acid (forming sulphate of aniline), and adding this to a solution of bichromate of potash (a deep red crystalline salt), a blue-black powder was obtained, from which he subsequently extracted the famous purple dye called *Mauve*—the French name for marsh-mallow.

This was the first coal-tar dye, and its discovery led scientific men of all countries to seek for further gems in the mysterious products of coal-tar. Nor did they seek in vain. In due time the world was again startled by the discovery of the superb red colour known as “Magenta,” or *fuchsine*, from its resemblance to the colour of fuchsia petals. The marvellous colouring power of some of the coal-tar dyes is such that it is calculated that one ten-millionth of a grain of magenta will give a red tint to a drop of water!

The extraordinary popularity which the brilliant “mauve” and “magenta” dyes received from the public was probably never surpassed in the long history of the art of dyeing. In the great “mauve” era every bonnet-shop, every linendraper’s window, and almost every member of the ribbon-loving sex exhibited the new purple as the glorious tint of the age. But how few were aware that the brilliant hue of the fascinating Bonnet Ribbon was derived from that nasty, sticky, black, strong-smelling, odious coal-tar!

As time rolled on, other coal-tar dyes made their appearance. Rich and brilliant blues, greens, oranges, and violets followed in quick succession; next came browns of various shades and tones of colour, with pinks and reds in every conceivable variety. But there was yet one other colour which chemists desired to

produce from coal-tar, and which they believed would be accomplished by further research and this was the colour which exists in the root of the *madder* plant (*Rubia tinctoria*), commonly called "dyers' madder."

The colouring principle of madder was first extracted by Robiquet, and received the name of *Alizarin*, from the Turkish *ali-zari*, which is the name given to a dye-stuff largely imported into this country from the Levant, Turkey, and Smyrna for the use of dyers and calico-printers.

To obtain from coal-tar the colouring principle of madder (alizarin) may be considered one of the greatest scientific triumphs of our time, and this great feat was accomplished by Græbe. Nor was the discovery a mere accident or scientific "fluke," but was the result of careful, well-directed research. It had long been known that a substance called by chemists *quinone* could be extracted from Peruvian bark, but it was not until Dr. Græbe determined the true nature of this substance, and proved that it closely resembled benzole in its chemical composition, that the road began to clear for the final discovery of alizarin. Dr. Græbe found that there were substances in coal-tar which were to others of the coal-tar series in the same chemical relation that quinone held with benzole. From this he concluded that alizarin was derived from one of these quinones. To get at this, Græbe and Liebermann first heated some alizarin with finely-powdered zinc, and obtained as a result a substance which crystallised in beautiful opalescent plates. This new substance was found to be identical with *anthracene*—a body discovered in coal-tar by the celebrated French chemists Dumas and Laurent as far back as 1832. The next thing Græbe and Liebermann had to determine was whether they could get *quinone* from *anthracene*. This had, however, already been accomplished by Dr. Anderson, who formed the

compound from anthracene by boiling it with nitric acid. To this substance Dr. Grœbe gave the name *anthraquinone*.

The method of preparing artificial alizarin is thus described by Messrs. Caro, Grœbe, and Liebermann in their patent specification, and, since it explains the manufacture of this most important colour with but little technicality, it will doubtless be perused with interest:—

“ In the one process we proceed as follows : — We take about one part by weight of anthraquinone, and about three parts by weight of sulphuric acid (specific gravity 1.488), and introduce the same into a glass or porcelain retort. The contents are then heated up to about 260° Centigrade (532° Fahr.), and the temperature maintained until the mixture is found no longer to contain any appreciable quantity of unaltered anthraquinone. The completion of this operation may be ascertained or tested by withdrawing a small portion of the product from time to time, and continuing the operation at the high temperature until such product, upon being diluted with water, is found to form a substantially perfect solution, thereby indicating that the anthraquinone has become either entirely or in greater part converted into the desired product.

“ The products thus obtained are then allowed to cool, and are diluted with water ; carbonate of lime is then added in order to neutralise and remove the excess of sulphuric acid contained in the solution. The mixture is then filtered, and to the filtrate carbonate of potash (or soda by preference) is added to the solution until carbonate of lime is no longer precipitated. The mixture is then filtered and the clear solution evaporated to dryness, by which means the potash (or soda) salts of the sulpho-acids of anthraquinone are obtained, and which are to be treated in the following manner :—

“ We take about one part by weight of this product, and

from two to three parts by weight of solid caustic soda, or potash : water may be added or not, but by preference we add as much water as is necessary to dissolve the alkali, after admixture. We heat the whole in a suitable vessel, and the heating operation is maintained at a temperature of from 180° C. (388° Fahr.) to 360° C. (532° Fahr.) for about one hour, or until a portion of the mixture is found upon withdrawing and testing it to give a solution in water, which, being acidulated with an acid (sulphuric acid for example), will give a copious precipitate of the colouring matters. The heating operation having been found to have been continued long enough, the resulting products are then dissolved in water, and we either filter or decant the solution of the same, from which we precipitate the colouring matter, or *artificial alizarin*, by means of mineral or organic acids, as, for example, sulphuric or acetic acid. The precipitated colouring matters thus obtained are collected in a filter or otherwise, and, after having been washed, may be employed for the purpose of dyeing or printing (calico-printing), either in the same way as preparations of madder are now used, or otherwise."

In their second process, the patentees obtain artificial alizarin from *anthracene* by operating upon that substance in the following way: "We take about one part by weight of anthracene, and about four parts by weight of sulphuric acid of the specific gravity of about 1.848,* and the mixture, being placed in a suitable vessel, is heated to a temperature of about 100° Cent. (212° Fahr.), and which is to be maintained for about three hours, the temperature being then raised to about 150° Cent. (334° Fahr.), which is to be maintained for about an hour, or until a small portion of the product, when submitted

* The specific gravity of water being 1,000, it will be seen that the sulphuric acid is nearly twice the weight of water.

to the two subsequent processes, hereafter described, is found to produce the desired colouring matters. We then allow the result obtained by this operation to cool, and dilute it with about three times *its own weight* of water. To this solution is added, for every part of anthracene, by weight, employed, from two to three parts of peroxide of manganese, in slight excess. The whole is then boiled for some time, and in order to fully ensure the desired degree of oxidation, the mixture may be subsequently concentrated, or evaporated to dryness, the heat being continued until a small quantity of the oxidised product, when submitted to processes hereafter described, will produce the desired colouring matters. We then neutralise and remove the sulphuric acid contained in the mixture, and at the same time precipitate any oxides of manganese that may be held in solution, by adding an excess of caustic lime, adding the same until the mixture has an alkaline reaction. We then filter, and add to the filtrate [the filtered liquor] carbonate of potash or soda, until there is no further precipitate of carbonate of lime. The solution is then filtered, and evaporated to dryness, and thus we obtain the potash or soda salts of what we call the *sulpho-acids of anthraquinone*."

The saline mass obtained as above is next treated with a solution of caustic soda or potash, as before, with the application of heat; and finally the resulting mixture is acidulated with hydrochloric or sulphuric acid, which precipitates the alizarin, which is afterwards washed and filtered, and is then ready for use.

It is remarkable that, whereas the earlier coal-tar dyes were produced from the lightest and most volatile product of coal (benzole), some of the later and equally brilliant dyes are obtained from the heavier and less volatile products—indeed from those which had for a long time been chiefly employed

as lubricants for machinery, and being to some extent looked upon as nearly waste products. But it is to these unexplored, unexamined, and therefore mysterious compounds that the scientist devotes his special attention. *There is something to be found out.* Something as yet unknown lies hidden in the heavy, oily fluid from which the light, ethereal benzole has been extracted; the less volatile *toluol*, and still less volatile *xylol*. By the process of *fractional distillation* and careful examination of each product obtained at different degrees of heat, the chemist now discovers in the comparative waste a mine of wealth!*

Aniline Purple, or Mauve. To prepare this beautiful dye, aniline is first converted into *sulphate of aniline* by saturating aniline with dilute sulphuric acid. The solution is afterwards evaporated until the sulphate separates. This salt is then dissolved in boiling alcohol, and when this cools crystals deposit in the form of brilliant colourless plates of pure sulphate of aniline, which is soluble in water.

To form the purple colour known as *Perkins' Purple*, a solution of bichromate of potash is added to a solution of the sulphate of aniline, when a blue-black precipitate is formed. This is first washed with water and then dried; it is next digested several times in benzole, and afterwards in boiling alcohol, to dissolve out the colouring matter, which is next purified by dissolving the residue in hot water, again precipitating with a solution of caustic soda, then washing the precipitate once more, and filtering. It is finally dissolved in alcohol, and then carefully evaporated to dryness, when a bronze-tinted substance is produced, resembling in appearance

* It is well known that enormous fortunes have been made by the various coal-tar dyes, and the subject is not yet considered as having been thoroughly worked out.

the surface of the wings of the well-known May-bug, or rose beetle, but not in the least degree exhibiting its actual colour, which is so cunningly disguised by the bronzed surface (which is something less than "skin" deep) that no tint of actual colour is visible.

If, however, a few minute particles of this deceptive substance be placed in warm water it will impart a vivid tint of purple at once. Or if a few grains be dropped upon a piece of white paper, and then roughly shaken off, and a little spirit of wine poured over the paper, the minute and invisible particles retained by the paper will be dissolved by the spirit, and at once become visible in the form of brilliant streaks of purple.

Aniline Red, or *Rose Aniline*. This intense and brilliant dye-stuff is known by many names, and prepared by various processes from aniline obtained from a product of coal-tar—benzole; and all the compounds are more or less beautiful specimens of coal-tar dyes. Bichloride of mercury, chloride of tin, arsenic, and other chemical substances, are made to react upon aniline, by which various tints of red are produced, such as magenta, fuchsine, roseine, &c.

The few examples we have given of the production of colours from the constituents of coal-tar will doubtless be sufficient to illustrate this part of our subject, and to satisfy the reader that from a Lump of Coal taken from the Pit's Mouth we can obtain those brilliant and beautiful dyes which of late years have added such a powerful charm to the flowing and fascinating Bonnet-Ribbon!

But not to the bonnet-ribbon alone, for our famous coal-tar dyes are extensively employed in dyeing all kinds of silk and woollen fabrics, and even cotton goods; indeed they have to a great extent superseded most of the old "dye-stuffs"

employed by our forefathers and are found to be more permanent or fast than many of the old dyes. Another advantage of the coal-tar dyes is that the colours can be produced upon the fabrics *direct* that is without mordanting and other processes usually employed in dyeing. To produce a purple dye formerly the fabric was first dyed *blue* in the indigo vat and afterwards dyed in a cochineal or madder bath while green colours were obtained by first dyeing the goods blue of any desired shade after which they were plunged in a *yellow* dye. These *compound colours* (purple and green) are obtained *direct* by means of the coal-tar dyes.

Manufacture of Coke. In the process of gas-making coke occurs naturally as a residual product after all the volatile matters of the coal have been expelled by the heat of the furnaces. A considerable portion of this gas coke is employed as fuel in the retort furnaces of the gasworks the surplus being sold at a moderate price to the public for domestic and other purposes. Besides this supply of coke however it is largely manufactured for heating the boilers of railway engines and is fuel for furnace fires.

There are many systems of coking coal as it is termed but the chief object in each is to *conserve* the volatile products of the coal that is to cause them to undergo *retention*, in which respect the process of coking may be considered exactly the reverse of *distillation* as conducted at the gasworks, whereby the volatile matters are collected and saved for various useful purposes as shown in the earlier portion of this book.

It is calculated that good coal when coked by the above plan is capable of yielding about 8 per cent of coke of excellent quality. It is estimated that coal while losing from 20 to 25 per cent in weight increases in bulk to the extent of about one fourth.

A rude system of coking, which has sometimes been adopted, consists of a chimney built of loose bricks, round which coal is packed in a circular heap. A series of small flues are formed between the lumps of coal, and these communicate with the chimney. The mass of coal is covered with "slack" and clay, and a series of openings is formed round the heap, from which it is kindled. The operation is known to be complete when smoke ceases to issue from the central chimney. Sometimes a heap or mound, somewhat resembling the stacking of mangold-wurzel, has been adopted; in building this, stakes of wood are placed vertically at different parts of the heap, and these are withdrawn after the mass has been covered with clay, and kindling material introduced into the apertures thus left. Certain small openings are made for the exit of the smoke and vapours.

In one arrangement of coking furnaces, a series of ovens is fixed in groups, each group communicating with a horizontal flue, which receives the volatile products of combustion. This flue is connected with a main shaft, or chimney, of considerable height, and the entrance to the chimney may be closed more or less, as occasion requires, by horizontal slabs of fire-brick, or "dampers," which regulate the draught of air, and this, entering in a small stream, causes complete combustion of the sooty matters, and thereby entire consumption of the smoke.

In charging the ovens, from three to four tons of coal are put into *each alternate oven*, and a quantity of straw is placed on the top of each charge, which, becoming ignited by the heat of the oven from the previous operation, sets fire to the smoke generated by the burning coal, and thus the smoke becomes "consumed" at the commencement of the operation, instead of passing up the chimney as soot. The principle of

igniting the volatile and inflammable products as they are generated, and thereby converting them into a *flame*, is of the greatest importance, for the continual stream of air which enters the flues supplies the burning mass with oxygen necessary to complete the combustion. To further assist this, the oven doors are also left open at this period of the operation—that is, while the chief soot-producing substances are being liberated from the burning coal. So perfect is the combustion of the inflammable matters that scarcely any smoke issues from the top of the shaft or chimney.

During the coking of coal by the above plan, the progress of the operation proceeds *from the top of the mass to the bottom*, so that a layer of fire always rests *above* the surface of the coal, and this consumes all the volatile products that are eliminated from the coal beneath. When the process of calcination is complete, the coal is deprived of all its inflammable and other volatile constituents. The ovens are then allowed to become somewhat cooled, by closing the dampers and opening the doors; after which the dull-red mass is raked out of the ovens, and is then quenched with water. When cold, the coke assumes a bright, glistening appearance, and is generally in much larger pieces or lumps than ordinary gas-coke.

Interesting Notes on Coal and its Products.

The *quality* of coal is determined by the quantity of water which a given weight of the coal will convert into steam, or by the quantity of litharge (oxide of lead) which it is capable of reducing to the metallic state.

One pound of good coal or coke will convert into vapour or steam about five pounds of water.

The chief sources of *bituminous* or *caking coals* are the districts of Newcastle and Wigan. The *cherry coal* or *soft coal* comes from Staffordshire, Glasgow, Derbyshire, Lancashire, &c. It is a very bright coal and ignites readily, but burns away quickly. *Splint* or *hard coal* forms the chief bulk of the coalfields of North and South Staffordshire, and occurs in the districts round Glasgow, as also in Warwickshire, Shropshire, and Leicestershire. This variety of coal does not readily ignite, but eventually makes up a clear fire, giving out a good heat. *Cannel* or *parrot coal* is found in Wigan and some other parts of Lancashire, as also in the neighbourhood of Glasgow. It is a very dense and compact coal, and may be worked into ornaments and polished like jet. It crackles and splinters in the fire, but burns very brightly, giving out considerable heat. There is a variety of coal called *boghead coal* or *torbanehill mineral*, somewhat resembling cannel coal, which is obtained from Bathgate, near Edinburgh.

The following description of a coal district, extracted from *Tomlinson's Cyclopædia of Arts*, gives a very accurate idea of scenes we have often witnessed in our travels through Staffordshire, and will doubtless be read with interest:—"In traversing much of the country included within the boundary of red

sandstone, the traveller appears never to get out of an interminable village, composed of cottages and very ordinary houses. In some directions he may travel for miles and never be out of sight of numerous two-storied houses ; so that the area covered with bricks and mortar must be immense. These houses, for the most part, are not arranged in continuous streets, but are interspersed with blazing furnaces, heaps of burning coal in process of coking, piles of ironstone calcining, forges, pit heads, and engine chimneys : the country being besides intersected with canals, crossing each other at various levels, and the small remaining patches of the surface soil occupied with irregular fields of grass or corn, intermingled with heaps of refuse of mines, or of slag from blast furnaces. Sometimes the road passes between mounds of refuse from the pit, like the deep cutting on a railway ; at others, it runs like a causeway, raised some feet above the fields, on either side, which have subsided by the excavation of the minerals beneath. In one place, observing that the turnpike road sloped a good deal on one side, I asked the driver if it would not be repaired : to which he replied they were still working the coal beneath it, and they would probably wait to see if the road would not right itself by sinking on the other side, and so become level again. The geologist would find no country more instructive for the study of the subsidence of dry land. The whole country might be compared to a vast rabbit warren. It is a matter of everyday occurrence for houses to fall down, or a row of buildings inhabited by numerous families to assume a very irregular outline, from what they call a *sway*, caused by the sinking of the ground into old workings. It is often a serious matter to find a sound site for a church or school building. There is an instance in the parish of Sedgely of a church and parsonage-house, recently

erected, composed of wooden framework which will admit of their being screwed up into the perpendicular again whenever they may be thrown out of it. Cellars beneath dwelling-houses are occasionally filled with choke damp, arising from old workings, to a degree that makes it dangerous to enter them. On one occasion a gentleman remarked that perhaps I was not aware that the steps by which I entered his house (in a town) were built on an arch covering the mouth of an old coal-pit. Early potatoes for the London markets are raised in ground near Dudley, heated by steam and smoke, which proceed from an old colliery which has been on fire for many years, and which may be observed bursting through the crevices of rock on the side of the road close to the town."

Coal-Gas as a Motive Power.—The first attempt to apply the extraordinary explosive property of coal-gas in combination with air, as a motive force in place of steam, was made as far back as 1824, by Mr. Brown, who took out a patent for his invention. This was doubtless the origin of the *gas-engine*—a machine which, under various names and in many forms, now holds an important place amongst the power-producing machines of our time. The following too sanguine extract from *Boyle's Chronology* (1824) fixes the date of this important invention, but for its practical development, we are indebted to more recent mechanicians:—"The invention of the gas vacuum engine will supersede the use of steam in working machinery. Mr. Brown's engine was examined by many scientific characters (!), and its efficacy universally acknowledged, and he obtained a patent for that invention."

In spite of the prophetic nature of the above announcement, it is only within the last few years that gas-engines have attained any degree of importance as compared with steam engines,

and indeed even the best of them have only succeeded in supplanting steam power within a very recent date. However, like all other things, the gas-engine had to make its way through prejudice and ignorance, and it may now be fairly considered as a recognised substitute for steam-power for certain purposes. Being an exceedingly convenient engine, and requiring but little attention when once started, it is now very extensively used, especially under circumstances in which a steam-boiler and engine could not be conveniently adopted. As a motive power for the dynamo-electric machines employed in electroplating, electrotyping, nickel-plating, and producing the electric light, gas-engines have proved to be very serviceable, from their greater convenience and uniformity of action.

As to the amount of gas required to produce one-horse power per hour, this has been estimated at 23 cubic feet; to obtain the same power from steam, six pounds of coal would be consumed. The cost of working gas and steam engines of the same horse power for a year would be about the same, for, although the former would require less manual attention, the cost of the gas would nearly counterbalance the wages of the driver of the steam-engine.

The following comparison in figures will show how nearly the yearly cost of gas and steam engines agree:—

12-horse power steam-engine: 6 lbs. of best steam coal per horse power per hour, $6 \times 12 \times 10^* \times 300^\dagger = 216,000$ lbs. = say $96\frac{1}{2}$ tons at	
18s.	£86 17 9
Engine-driver's time, 3,000 hours at 6d. per hour	75 0 0
	<hr/>
	£161 17 0

* Working hours.

† Working days.

Gas-Engine :

The best gas-engine is stated to consume 23 cubic feet of gas per horse power per hour,
 $23 \times 12 \times 10 \times 300 = 823,000$ cubic feet, at the average all-England rate of 3s. 9d. . . . £155 5 0

Attendant's time, starting, cleaning, lubricating, &c., say one hour per day = 300 hours at 6d. . . . 7 10 0

£162 15 0

The horse power of a steam-engine is thus estimated :—One-horse power is equal to a force which will raise a weight of 33,000 lbs. one foot per minute.

According to one authority, one nominal horse power requires about 15 pounds of coal and 5 gallons of water per hour, with 1 square yard of heating surface and 1 square foot of firebar surface.

The heat disengaged during combustion of

Coal is	8,000°
Coke	7,000°
Dry Wood	4,025°
Hydrogen Gas	34,462°
The heat of an ordinary fire is	2,141°
Blast furnace (white heat)	3,300°

From the famous Bog of Allen, in Ireland, peat of remarkable quality is obtained, and some specimens which the author has had in his possession appeared to have advanced far on the road to conversion into coal. Trunks of trees as black as ebony (commonly known as "Irish bog-oak") are dug out of this and other bogs in perfect preservation, and the wood is largely employed in the manufacture of bracelets, brooches, snuff-boxes, and many other articles of utility or

ornament. While the bog-oak, however, is intensely black, a specimen of bog-yew in the author's possession is of a light-brown colour. Although it may be conjectured that the bog-wood and peat may, in centuries to come, be transformed into coal, the semi-petrified vegetable matter is not subjected to the pressure and subterranean heat which probably hastened the formation of the coal discovered in the lower depths of the earth—the *coalfields*, commonly so called.

The effect of an explosion in a coal mine is thus graphically described by Dr. Ure, in his *Dictionary of Arts, Manufactures, and Mines*:—"The catastrophe of an explosion in an extensive coal mine is horrible in the extreme. Let us imagine a mine upwards of 100 fathoms deep, with the workings extended to a great distance under the surrounding country, with machinery complete in all its parts, the mining operations under regular discipline, and railways conducted through all its ramifications; the stoppings, passing doors, brattices, and the entire economy of the mine, so arranged that everything moves like a well-regulated machine. A mine of this magnitude at full work is a scene of cheering animation and happy industry; the sound of the hammer resounds in every quarter, and the numerous carriages, loaded or empty, passing swiftly to and fro from the wall faces to the pit bottom, enliven the gloomiest recesses. At each door a little boy, called a trapper, is stationed, to open and shut it. Every person is at his post, displaying an alacrity and happiness pleasingly contrasted with the surrounding gloom. While things are in this merry train, it has but too frequently happened that, from some unforeseen cause, the ventilation has partially stagnated, allowing a quantity of the fire-damp to accumulate in one space to the explosive pitch; or a blower has suddenly sprung forth,

and the unsuspecting miner, entering this fatal region with his candle, sets the whole in a blaze of burning air, which immediately suffocates and scorches to death every living creature within its sphere, while multitudes beyond the reach of the flame are dashed to pieces by the force of the explosion, rolling like thunder along the winding galleries. Sometimes the explosive flame seems to linger in one district for a few moments ; then, gathering strength for a giant effort, it rushes forth from its cell with the violence of a hurricane and the speed of lightning, destroying every obstacle in its way to the upcast shaft. Its power seems to be irresistible. The stoppings are burst through, the doors are shivered into a thousand pieces ; while the unfortunate miners, men, women, and boys, are swept along with an inconceivable velocity, in one body, with the horses, carriages, corves, and coals. Should a massive pillar obstruct the direct course of the aerial torrent, all these objects are dashed against it, and there prostrated or heaped up in a mass of common ruin, mutilation, and death. Others are carried directly to the shaft, and are either buried there amid the wreck, or are blown up and ejected from the pit mouth. Even at this distance from the explosive den, the blast is often so powerful that it frequently tears the brattice walls of the shaft to pieces, and blows the corves suspended in the shaft as high up into the open air as the ropes will permit. Not unfrequently, indeed, the ponderous pulley-wheels are blown from the pit-head frame, and carried to a considerable distance in the bosom of a thick cloud of coals and coal-dust brought up from the mine by the fire-damp, whose explosion shakes absolutely the superincumbent solid earth itself with a mimic earthquake. The dust of the ruins is sometimes thrown to such a height above the pit as to obscure the light of the sun. The silence which succeeds

to this awful turmoil is no less formidable; for the atmospheric back-draught, rushing down the shafts, denotes the consumption of vital air in the mine, and the production of the deleterious choke-damp and azote (nitrogen).

“Though many of the miners may have escaped by their distance in the workings from the destructive blast and the fire, yet their fate may perhaps be more deplorable. They hear the explosion, and are well aware of its certain consequences. Every one, anxious to secure his personal safety, strains every faculty to reach the pit-bottom. As the lights are usually extinguished by the explosion, they have to grope their way in utter darkness. Some have made most marvellous escapes, after clambering over the rubbish of fallen roofs, under which their companions are entombed; but others, wandering into uncertain alleys, tremble lest they should encounter the pestilential airs. At last they feel their power, and, aware that their fate is sealed, they cease to struggle with their inevitable doom; they deliberately assume the posture of repose, and fall asleep in death. Such has been too often the fate of the hardy and intelligent miners who immure themselves deep beneath the ground, and venture their lives for the comfort of their fellow-men; and such frequently is the ruinous issue of the best ordered and most prosperous mining concerns.”

Before the discovery of the Davy Lamp, mining operations were conducted by the aid of small candles having very small wicks, which were found to give a brighter flame than larger candles with stouter wicks. Previous to commencing operations, it was the custom, and is still to some extent, to ascertain the condition of the air in the pits by means of the flame of a candle, which exhibits various differences of form and colour according to the nature of the atmosphere in which it is burnt.

The operation of testing the air is called *trying the candle*. The wick of the candle is first carefully trimmed by cutting off the superfluous snuff. When burnt in ordinary air, the flame assumes the form of a bright yellow cone, with a light blue fringe at its base, near the wick. If the hand be held before the candle, at about an inch from it, so as to expose only the extreme point of the flame, a luminous top, as it is termed by miners, becomes visible. This is of a brownish-yellow colour, and about a quarter of an inch in length, of a misty appearance. The miners avail themselves of the difference in colour and form which the misty top of the flame assumes when burnt in common air, air containing carbonic acid, or air containing "fire-damp" (coal gas). When carbonic acid or nitrogen is largely present in the air, the top of the flame becomes elongated to the extent of an inch or more, and of a darker brown colour. If there is a still greater quantity of carbonic acid or "fixed air" in the mine, the flame becomes extinguished, and the men at once withdraw. When entering workings of a doubtful character, the miners advance very cautiously, candle in hand, and carefully watch the character of the flame as they progress. If the top of the flame changes to a bluish-grey colour, and this becomes more and more blue, it indicates the presence of a dangerous quantity of coal-gas. The miner in such case is careful not to make any sudden movement of his body, lest by doing so he should disturb the inflammable air, and thus endanger not only his own life, but the lives of his comrades. Coal-gas, being lighter than the air, naturally ascends to the roof of the working; therefore, the miner, when he discovers, by the appearance of his candle flame, that there is a dangerous accumulation of fire-damp, lowers his candle carefully towards the pavement, or extinguishes it with his finger and thumb, and then gropes his way back.

Lignite, or brown coal, has the appearance of being only partially mineralised or converted into coal. Lignites are distinguished from "true coals" by their giving but little flame, while yielding abundance of smoke. In Germany this species of coal is much used for obtaining paraffin and burning oils.

Artificial, or "economical," fuel is sometimes made from coal dust or "breeze" by mixing one part of small coal, one part of clay or loam, and two parts sand or ashes; the whole is worked up into a thick mass with a little water and then rolled up into convenient-sized balls, which are afterwards dried. These balls are piled on the fire, and are reputed to give out considerably more heat than coal, at less than half the cost. At the same time the fire requires no stirring, and will burn steadily for eight or ten hours without the addition of fresh fuel.

Small Welsh coal and pitch have also been worked up together to form artificial *steam fuel*. The pitch is first broken up into small pieces; it is then well mixed with small coal in iron pans, heated by a furnace fire. The mass is kept well stirred by means of a vertical shaft, furnished with several blades. The mixture is afterwards submitted to immense pressure in iron moulds.

Another useful artificial fuel is prepared by mixing together 1 cwt. of coal-dust and 20 lbs. coal-tar pitch. These are fused together by moderate heat, and the mass is afterwards pressed by powerful machinery into blocks about the size of ordinary bricks, which are afterwards coated with whitewash.

Anthracite or *stone coal* differs greatly from all other species of coal. It burns without flame or smoke, and yields an intense heat, leaving but little ash. It does not burn well in an ordinary fireplace, unless there is a good draught in the

chimney. This coal is used largely in America, and is generally kindled with charcoal, fresh fuel being required not oftener than once or twice a day. A fire made with anthracite coal requires no poking. It is a very good and economical plan to mingle a little anthracite with ordinary coal for domestic purposes.

In an interesting dissertation on the geology of coal* the professors of the Yorkshire College make the following observations respecting the probable process by which cannel coal was formed:—"Cannel coals always occur in dish-shaped patches thinning away to nothing on all sides; they frequently merge insensibly into highly carbonaceous black shale, and they contain occasionally the remains of fish.

"The presence of fossil fish in cannels shows that they must have been formed under water, and they probably consist of vegetable matter which was drifted down into ponds or lakes, and lay soaking till it became reduced to a pulp. The deposit was, of course, limited in extent by the banks of the sheet of water in which it was formed, and hence the lenticular shape which beds of cannel exhibit. A certain amount of mud would, of course, be brought into the water along with the drifted plants, but being heavier than they it would fall down, first carrying with it enough decomposing vegetable matter to stain it black; in a certain distance all the mud came to the bottom, and the vegetable residue floating on sank slowly, and became spread out over the bed of the lake further on. Thus near the mouth of a river deposits of laminated carbonaceous mud were laid down, and these gradually contained less and less mud and more and more vegetable matter till they merged into a mass of vegetable pulp.

* Coal: Its History and Uses. Edited by Prof. Thorpe.

“The maceration it has undergone to a large extent effaced all traces of vegetable structure in cannel coal, but spores can now and then be detected in it.”

Dr. Hull gives the following estimate of the annual production of coal in different countries :—

	Tons.
Great Britain and Ireland (1879)	134,008,228
America. U.S. (1877)	54,398,250
„ Nova Scotia (1879)	688,626
France (1877)	16,877,200
Belgium (1878)	14,899,175
Germany, Coal and Lignite (1877)	48,296,367
Austrian Empire (1876)	14,252,038
Spain (1873)	699,500
Russian Empire (1876)	1,824,868
British India	500,100
New South Wales (1877)	1,444,271
Vancouver Island (1878)	145,542
Queensland (1877)	60,918
Dominion of Canada : Cumberland, Picton (Nova Scotia), Cape Breton	757,496

The above statements and estimates give an approximate view of the output of coal over the globe, amounting to about 289 millions of tons per annum. Thus man by his progress in the arts is gradually restoring to the atmosphere the carbonic acid which was extracted therefrom during the carboniferous period. Much of this is taken up and utilised by vegetation; but, as it is probable that the consumption of vegetable matter is at least equal to the growth, there is a tendency towards deoxidation.

A new method of working coal has lately been discovered

which will tend greatly to diminish the danger attendant on breaking down large masses of this substance.

“Considerable attention is just now being taken in the new system of getting coal by means of lime cartridges, which are in regular use at the Sheply Collieries, Derbyshire. In addition to the fact that trials have been made in various parts of the country with a view of testing the new method, a visit has recently been paid to the colliery by the officials of the Miners’ National Union for the purpose of inspecting the system at work. Amongst those who descended the workings were Mr. Burt, M.P. (President), Mr. B. Picard (Vice-President), and Mr. Crawford (Secretary), &c., &c. Some of them were much impressed with what they saw, and have given notice to lay the matter before the Miners’ National Conference, to be held at Manchester. The notice for discussion is as follows:—‘That we urge upon the Home Office the necessity of finding means to test the principle of bringing into use the new system of getting coal with lime.’ When the party visited the mine, they were conducted into a stall about 100 yards in length, where they found a large quantity of coal had been brought down by the new process, and lay ready for piling in large blocks. Workmen then prepared a number of holes, about one yard and three inches in depth, the time of drilling each of which did not exceed six minutes and a quarter. Four cartridges were put into each hole, and were then saturated with water, and in less than twenty seconds the coal began to crack and was forced down in large blocks. The party were much impressed with what they had seen, and it is understood that, in addition to the easy mode of getting coal, the system will be recommended, owing to its enabling miners to remove coal without having to resort to blasting or drilling, thus making it valuable in the seams

which are wrought in Yorkshire and other coalfields. It is also said to be even quite as economical as blasting, whilst the coal is brought down in much larger and more saleable blocks. A trial of the system has been made at one of the largest collieries in South Yorkshire, where the measures worked are subject to those sudden outbursts of gas from the roof and floor, necessitating the strict use of the very best safety lamps, accompanied by strict discipline."—*Iron*.

The following figures show how greatly the coal produce of Great Britain has increased since the year 1854. In that year the produce of England, Scotland, and Wales combined was 64,661,401 tons.

In 1861 the produce was :-	Tons.
England and Wales	80,262,873
Scotland	12,400,000
Ireland	125,000
Total	92,787,873

In 1874 the produce was :	
England and Wales	108,140,042
Scotland	16,788,651
Ireland	139,213
Total	125,067,916

In 1879 the produce was : -	
England and Wales	116,409,301
Scotland	17,469,927
Ireland	129,000
Total	134,008,228

The late Professor Phillips calculated the probable time

occupied in producing the famous coalfield of South Wales, and based upon the supposition that the sedimentary materials had been formed at the mouth of a large river, as the Ganges, for example, and the carbonaceous portions to have been stored up at the rate of one inch in 127·2 years, the result arrived at would be about half a million years.

List of deaths from colliery accidents during a period of ten years, compiled by Mr. Atkinson, one of the Government Inspectors : -

Causes of Death.	No. of Deaths.	Proportion per cent.	Amounting to
Deaths resulting from fire-damp explosions	2,019	20·36	{ About one-fifth.
Deaths resulting from falling roofs and coals	3,953	39·87	{ About two-fifths.
Deaths resulting from shaft accidents	1,710	17·24	{ Less than one-fifth.
Deaths resulting from miscellaneous causes and above ground	2,234	22·53	{ More than one-fifth.
	9,916	100·00	

Mr. Allan Bagot, in his valuable work on "The Principles of Colliery Ventilation," says, "There are two general methods of ventilation in collieries : one by means of a furnace at the foot of the upcast shaft, and the other by means of a vacuum fan at the top of the upcast shaft, which latter system (by reason of the depression caused in the vacuum chamber brought about by the rapid rotation of the fan) sucks air out of the pit, or, more accurately speaking, causes the air in the upcast shaft to ascend to fill the depression in the vacuum chamber, and so permits a current of air flowing through the pit.

"The action of the furnace system in producing a current of

air is as follows :—A mine is simply a V-shaped tube, and it will be at once seen that the two upright columns of air in the arms of the tube must balance each other, or if one is lighter than the other the heavier column will descend and push the other up until equilibrium is produced, when the motion of the respective air columns will cease until further alteration takes place in the respective weights of the two columns, and it will be seen that if the difference in weight of the two columns is constant the motion and the velocity of the whole of the air in the tube will also continue constant and in one and the same direction.”

According to Mr. Leifchild, the following table represents the output of coal in the United Kingdom for the year 1872 :—

	Tons.
South Durham	17,395,000
Northumberland	13,000,000
Yorkshire	14,536,000
Derbyshire	10,660,000
Lancashire and North Wales . .	18,363,236
North Staffordshire	16,877,188
Gloucester and Somerset . . .	7,000,000
South Wales	10,131,725
Scotland	15,383,609
Ireland (estimate for 1872) . .	200,000
	—
	123,546,758

In reference to the formation of coal Dr. Hull remarks :—
 “ There are two conclusions which strike us most forcibly when reflecting on the formation of our coalfields: the enormous subsidence of the original surface, and the lapse of time it must have required to produce a series of strata with their coal seams

in all several thousand feet in thickness. Recollecting that every bed of true coal represents a land surface, or at least a sea level, when we find, as in the case of the coalfield of South Wales, or of Nova Scotia, strata with coal beds through a thickness of 10,000 or 12,000 feet, it is evident that this is a measure of the actual sinking of the surface for this geological period; or to take an example: The height of Mont Blanc is about 15,000 feet; now the vertical displacement which the South Wales coalfield underwent was nearly sufficient to have brought the summit of the Alps to the sea level.

“Of the lapse of time in the formation of our coalfields we can have but a faint conception; it is only to be truly measured by Him with whom ‘a thousand years are but as one day.’ But the magnitude of the time is only surpassed by the boundlessness of the Providential care which laid up these terrestrial treasures in store for His children whom He was afterwards to call into living.”

The following elements are found in coal: Aluminium, Calcium, Carbon, Hydrogen, Iron, Magnesium, Nitrogen, Oxygen, Phosphorus, Potassium, Silicon, and Sulphur.

The following table by Mr. Leifchild shows the number of persons employed in each district, with the average number of tons raised by each person in the year 1872:—

	Persons employed.	Average tons.
South Durham	45,300	384
Northampton	39,000	333
Yorkshire	51,056	285
Derbyshire	39,200	271
North Staffordshire	27,555	228
South „	31,500	335

	Persons employed	Average tons
Lancashire West	28,657	326
, North	34,000	261
Gloucester	27,300	256
South Wales	38,427	263
Scotland West	20,639	307
East	30,000	301

While the principal portion of this work was at press the British Association held its fifty-second meeting at Southampton when Dr. Werner Siemens, the new President, delivered the inaugural address which, in many respects, may be considered one of the most remarkable and far-sounding we will not say prophetic utterances which have been listened to by learned ears for many a day. It will never be justly said of Dr. Siemens that he is either crotchety, wildly speculative, or given to flights of mere imagination. Being a man of sound knowledge and deep research, he is also thoroughly practical in developing or fitting into use the products of his reasoning. There may be some who differ from his views, but probably few able to refute them.

Amongst other interesting topics Dr. Siemens made special reference to Coal, and since it is possible that some of our readers may not have read his remarks which are specially applicable to a work of this nature, we have much pleasure in reproducing some of them. Before doing so, however, a few observations of the late President Sir John Lubbock will be read with interest.

Speaking of Dr. Siemens, Sir John Lubbock said:—‘If the ruling idea of his life had been to economise energy and utilise the forces of Nature, and they might look forward the time when the winds and tides would, to a great extent, replace the furnace and the steam engine, so that Britain

would rule the waves in a new and more peaceful sense. If any one could, Dr. Siemens would stop the waste of Coal now hanging in a smoky pall over our great cities, and restore to them pure air, bright sunshine, and blue skies. Though our Coal, however economised, must one day be exhausted, we might by that time be able to store up summer heat for winter use."

In speaking of the relative cost of electricity and gas as illuminating powers, and as to the prospect of the former usurping the place of the latter—which to a great extent will, no doubt, be the case hereafter—Dr. Siemens says:—"Assuming the cost of electric light to be practically the same as gas, the preference for one or other would in each application be decided upon grounds of relative convenience, but he ventured to think that gas-lighting would hold its own as the poor man's friend. Gas was an institution of the utmost value to the artisan; it required hardly any attention, was supplied upon regulated terms, and gave, with what should be a cheerful light, a genial warmth, which often saved the lighting of a fire. The time was, moreover, not far distant when both rich and poor would largely resort to gas as the most convenient, the cleanest, and the cheapest of heating agents, and when raw coal would only be seen at the colliery or gas-works.

"In all cases where the town to be supplied was within, say, thirty miles of the colliery, the gas-works might with advantage be planted at the mouth, or still better at the bottom of the pit, whereby all haulage of fuel would be avoided, and the gas, in its ascent from the bottom of the colliery, would acquire an onward pressure sufficient, probably, to impel it to its destination. The possibility of transporting combustible gas through pipes for such a distance had been proved at Pittsburg, where

natural gas from the oil district was used in large quantities. The quasi-monopoly so long enjoyed by gas companies had had the inevitable effect of checking progress. The gas being supplied by meter, it had been seemingly to the advantage of the companies to give merely the prescribed illuminating power, and to discourage the invention of economical burners, in order that the consumption might reach a maximum. The application of gas for heating purposes had not been encouraged, and was still made difficult in consequence of the objectionable practice of reducing the pressure in the mains during daytime to the lowest possible point consistent with prevention of atmospheric in-fraught. The introduction of the electric light had convinced gas managers and directors that such a policy was no longer tenable, but must give way to one of technical progress. New processes for cheapening the production and increasing the purity and illuminating power of gas were being fully discussed by the Gas Institute, and improved burners rivalling the electric light in brilliancy greeted their eyes as they passed along the principal thoroughfares."

According to Dr. Siemens, the annual value of products of a gas-works other than gas, including colouring matter, sulphate of ammonia, pitch, creosote, crude carbolic acid, and gas-coke is estimated at £8,370,000, or nearly three millions above the value of the coal used. In using raw coal for heating purposes, these valuable products are not only absolutely lost to us, but in their stead we are favoured with these semi-gaseous by-products in the atmosphere, too well known to the denizens of London and other large towns as smoke.

"Mr. Aiken has shown, moreover," says Dr. Siemens, "that the fine dust resulting from the imperfect combustion of coal was mainly instrumental in the formation of fog: each particle

of solid matter attracting to itself aqueous vapour. These globules of fog were rendered particularly tenacious and disagreeable by the presence of tar vapour, another result of imperfect combustion of raw fuel, which might be turned to better account at the dye-works. The hurtful influence of smoke upon public health, the great personal discomfort to which it gave rise, and the vast expense it indirectly caused through the destruction of our monuments, pictures, furniture, and apparel, were now being recognised.

“The most effectual remedy would result from a general recognition of the fact that wherever smoke was produced fuel was being consumed wastefully, and that all our calorific effects, from the largest down to the domestic fire, could be realised as completely, and more economically, *without allowing any of the fuel employed to reach the atmosphere unburnt*. This most desirable result might be effected by the use of gas for all heating purposes, with or without the addition of coke or anthracite.”

Before many years have elapsed, Dr. Siemens predicts, we shall find in our factories and on board our ships engines with a fuel consumption not exceeding one pound of coal per effective horse-power per hour, in which the gas-producer will take the place of the somewhat complex and dangerous steam-boiler; and that the advent of such an engine, and of the dynamo machine, must mark a new era of material progress at least equal to that produced by the introduction of steam power in the early part of our century.

The two and three necked bottles in Figure 7 (page 33) were invented by Peter Woulfe, or Woolfe, an eminent alchymist, who resided in Barnard's Inn, London, in the latter part of the last century.

Mr. Leifchild, in his interesting work on *Coal at Home and Abroad*, makes the following observations on the advantages of the Safety Lamp :—

“ One of the foremost among the many advantages of the Davy Lamp is its value as a sure and simple indicator of the presence of fire-damp, and, therefore, of danger. Every morning, before work begins, a subordinate officer, named an *overman*, or deputy, perambulates the working places of the pit, and, with his Davy in his hand, carries the test of safety, and the measurer as well as the indicator of danger. If his lamp show a tall cap or halo, and an enlarging flame, he at once knows that the hewers of coal who are to follow him must be warned of the peril, and in case of much explosive air a rude signal is so placed as to warn off the hewers altogether from the place. Men who disregard this warning do so in defiance of death. The overman himself incurs the first risk, and measures it, and hence he ought to be much better acquainted with the principles of the Davy and the chemistry of gases than he commonly is. Upon his preliminary survey, and that of his colleagues, depends the safety of the whole company of workmen underground. Many of these deputies are uneducated, and ignorant to a lamentable degree.”

As to the quantity of coal raised in Great Britain in comparison with the produce of other countries, Mr. Leifchild says :—

“ That our commercial prosperity is founded upon the possession and use of coal is sufficiently known as a general truth, but the whole state of the case is not so widely understood. Great Britain has become the working coalfield of the world. We have for some years been raising more than half the total coal raised in all parts of the globe, and we have recently

raised considerably more than half that total, which, in 1866, was estimated at 170,430,544 of tons. If the whole world may now be supposed to raise annually about 200,000,000 of tons, we are raising about 120,100,000 out of the 200,000,000. Yet with this immense extraction we have only about 32,000,000 of inhabitants in the United Kingdom."

"It is melancholy to contemplate," says the same writer, "a necessary importation of coal to a country which, by its possession and utilisation, has dominated the manufacturing world. It will, indeed, be a kind of moral retribution, when we, the great and prodigal exporters of coal, or rather our less fortunate descendants, shall come to beg abroad for the mineral we have for a century been sending away. We have had coal enough and to spare, but we have squandered our inheritance, and, alas! may be severely punished."

"The deeper a mine is," wrote the late Stanley Jevons, "the more fiery it in general becomes. Carburetted gas, distilled from the coal in the course of geological ages, lies pent up in the fissures at these profound depths, and is ever liable to blow off and endanger the lives of hundreds of persons. It was supposed that George Stephenson and Sir H. Davy had discovered a true safety lamp. But, in truth, this very ingenious invention is like the compass that Sir Thomas More describes in his *Utopia* as given to a distant people. It gave them such confidence in navigation that they were 'farther from care than danger.'"

Professor Roberts calculates that the soot hanging over London on a winter's day amounts to fifty tons, and that the carbonic oxide—a deleterious product of coal—amounts to at least five times that quantity.

Without coal as a native product, our vast store of iron and other metallic ores would be comparatively worthless to us. It will be an awkward day for England when she will be dependent upon foreign coal for manufacturing purposes !

It is a noticeable fact that the colours obtained from coal-tar, which exhibit most wonderful *staining* powers, do not possess what painters call *body*. They are, in fact, in any condition in which they can be used, *transparent*, whereas "body colours," as chrome yellow, red lead, vermillion, and all mineral colours, are all more or less *opaque*. The aniline colours, therefore, more closely resemble the vegetable colours, gamboge, indigo, madder, &c.

Aniline is obtained from *indigo*, and also from coal-tar.

Benzole is obtained from *benzoic acid* (a substance derived from gum benzoin), and also from coal-tar.

Alizarine is obtained from *madder*, and also from coal-tar.

Coal was first brought into London by railway in 1845, when about 8,000 tons were thus conveyed into the metropolis. In 1880 the amount increased to upwards of six millions of tons.

The consumption of coal in London is estimated at about 13 per cent. of the entire produce of Great Britain. In 1823 the amount of coal brought to London was about 1,575,405 tons, whereas in 1880 it was nearly ten millions of tons.

After reading the calculations of Sir William Armstrong and the late Professor Jevons as to the probable duration of coal (page 4), the following estimates of the entire quantity of coal in the United Kingdom (furnished under Government

authority) will be very consoling to our readers. For our future use we are supposed to have, in the aggregate, 146,180,285,398 tons. "Of this quantity," says Mr. Meade,* "90,207,285,398 tons exist at depths not exceeding 4,000 feet in known coalfields, and 56,273,000,000 tons as the probable amount of coal under Permian and other overlying formations at depths of less than 4,000 feet; 40 per cent. being deducted for loss and other contingencies.

"The details of quantities under the first head, Visible Coalfields, appear in the annexed table from the Coal Commission Report (1871). Side by side are given the quantities of coal remaining and available for future use from 1880, amounting to 79,015,613,038 tons, divided as follows in the Visible Coalfields of the United Kingdom:

	Tons.
England and Wales	69,192,056,317
Scotland	9,669,172,642
Ireland	154,384,079
	—
Total known coalfields	79,015,613,038
Concealed	56,273,000,000
	—
Total coal available, 1880	135,288,613,038
	—

"With these available resources, and an annual output of nearly 147 millions of tons, supplies are yet ensured for 920 years hence."

Doubtless many of our readers have either seen or heard of "Judson's Dyes," which have for many years past been placed before the public in a convenient form for domestic use, &c. It will not be considered that we are "puffing" the enterprising firm whose name they bear if we make a slight allusion to the

* "Coal and Iron Industries of Great Britain," by Richard Meade.

eat and practical way in which they have placed the beautiful coal-tar dyes within the reach of the general public. In small bottles, labelled with practical directions, every variety of colour is provided at a trifling cost, while the contents of each bottle is amply sufficient to dye a good many small articles, such as scarves, ribbons, neckties, &c. There is much real service rendered to private families by thus enabling them to renovate or alter the colour of a silk or woollen article in a few moments at the cost of at most a few pence.

As far back as A.D. 852 there is a record of the Abbey of Peterborough having received twelve cartloads of fossil or pit coal.

“In the reign of Henry III., A.D. 1239,” writes Mr. Meade, “a charter was granted to the freemen of Newcastle-upon-Tyne to dig coals in the Castle fields, and it appears that it was about this time that coal was first sent to London. About the end of Edward I.’s reign A.D. 1305, considerable quantities of coal were used by brewers and smiths; this was followed by numerous complaints being made of the injurious effects of the smoke. The burning of coal was prohibited, and by commission from the king fines were levied to prevent it. Nothing appears to have resulted from this prohibition, as coals are said to have been used a few years later on the king’s coronation. In Edward III.’s time a licence was granted to the freemen of Newcastle to work coals within the town’s walls, and about A.D. 1367 coals were also worked in the neighbourhood of Winlaton, near Newcastle.”

Referring to the plants which have been discovered in coal, or “coal plants,” as they are called, Mr. Bowen says: “By far the most numerous, the most beautiful, and the best preserved fossils in the coal measures are those of the family of ferns. I

have more than 200 specimens in my collection belonging to this extensive family. Most of the species, however, are only represented by their leaves, or by the slender stems to which they are attached. Notwithstanding their great abundance, I do not believe their vegetation contributed materially, if anything, to the formation of coal. I shall presently give my reasons for this opinion, since, from their abundance in the coal measures, nearly all geologists have inferred that they contributed the great bulk of the solid coal.

“The fossil ferns comprise the following genera, all of which are determined by the character of their leaves or fronds:—*Pachypteris*, or thick fern; *Sphenopteris*, or wedge fern; *Cyclopteris*, or circular fern; *Glossopteris*, or tongue-shaped fern; *Neuropteris*, or nerve fern; *Odontopteris*, or tooth fern; *Anomopteris*, signifying secret fern; *Tectopteris*, or wreath fern; *Pecopteris*, of unknown significance; *Longchopteris*, or spear-shaped fern; *Schizopteris*, or divided fern; *Otopteris*, resembling the ear; and *Cantopteris*, a stem-like fern.”

“The purer part of the Brora (Sutherlandshire) coal,” writes Dr. Ure, “resembles common pit-coal, but its powder has the red ferruginous tinge of pulverised lignites. It may be considered one of the lost links between lignite and true coal, approaching very nearly in character to jet, though less tenacious than that mineral, and, when burnt, exhaling but slightly the vegetable odour so peculiar to all imperfectly bituminised substances. The fossil remains of shells and plants prove the Brora coal to be analogous to that of the eastern moorlands of Yorkshire, although the extraordinary thickness of the former, compared with any similar deposit of the latter (which never exceeds from 12 to 17 inches), might have formerly led to the belief that it was a detached and anomalous deposit of true coal,

rather than a lignite of any of the formations *above* the new red sandstone : such misconception might more easily arise in the infancy of geology, when the strata were not identified by their fossil organic remains."

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The same authority gives the following as the arrangement of the different strata in the Yorkshire coalfields : " On the coast of Yorkshire the strata of this pseudo coal formation appear in the following order, from Filey Bay to Whitby : 1. Coral-rag : 2. Calcareous grit ; 3. Shale, with fossils of the Oxford clay ; 4. Kelloway rock (swelling out into an important arenaceous formation) ; 5. Cornbrash ; 6. Coaly grit, of Smith : 7. Pierstone (according to Mr. Smith, the equivalent of the great oolite) ; 8. Sandstone and shale, with *peculiar plants and various seams of coal* ; 9. A bed with fossils of the inferior oolite ; 10. Marl-stone ; 11. Alum-shale or lias. All the above strata are identified by abundant organic remains."

The use of gas in lighting the houses and streets in London was brought into common use in 1809.

The amount of sulphur in coal is of great importance in the manufacture of good coal-gas, and when it exists to the extent of more than one per cent. the gas produced will be of inferior quality, unless carefully purified. If there is over two per cent. of sulphur in coal it is unfit for domestic purposes. The presence of a large proportion of mineral or earthy matters is also highly objectionable in coal, since they become fused into vitreous masses called "clinkers," which block the passage of the air through the fire-bars, and this necessitates their being constantly raked out by the fire-tenders.

There are few persons who have not known the discomfort

of a "smoky chimney" - a nuisance which is believed to be preventible by having the chimney properly constructed when the house is built. There are, however, other causes of chimneys smoking, which may be removed by judicious attention to several matters which should never be neglected. When a damp and heavy atmosphere descends into the chimney during the night, which is frequently the case, it is necessary to drive it out of the chimney before lighting the fire. This may be done by putting paper in the grate and lighting it *before* "laying" the fire. The hot air thus produced will ascend into the chimney and expel the cold and denser air. If the flame or smoke of the lighted paper enters the apartment, instead of passing upward, fresh paper must be lighted, and until there is positive evidence of an upward draught the wood and coal should not be ignited. Sometimes, in spite of this precaution, the smoke will pass into the room in fitful gusts, owing to a downward draught. This may often be remedied by partially opening the window, or by opening the front or a back door (according to the direction of the wind) partially even to the extent of only one inch. Mr. Cooley's views upon this subject are very instructive and interesting :-

"Let a fire be kindled in the grate ; hot air is evolved, the chimney is heated, the air it contains suffers expansion, and a portion is expelled. The chimney now contains a smaller weight of air than it did before ; the external and internal columns no longer equilibrate each other, the warmer and lighter air is forced upwards from below, and its place is occupied by cold, and consequently heavier air. If the fire continues to burn, and the chimney retains its temperature, this second portion of air is disposed of like the first, and the ascending current continues, so long as the sides of the chimney are hotter than the surrounding air. Should the

reverse happen to be the case, as sometimes occurs from sudden atmospheric changes, the column of air within the chimney rapidly contracts in volume, the deficiency is filled up from without, the column of air becomes heavier than one of a corresponding height on the outside of it, or in the apartment, and obeying the common laws of gravitation, it falls out of the throat of the chimney or fireplace, just as a heavy body sinks in water, and has its place occupied by air from above. In this way a descending current, of more or less intensity and duration, is established, and, if there is a fire in the grate, the chimney ‘smokes,’ or, if the grate is empty, perhaps the smoke from neighbouring chimneys finds its way into our apartments. By the judicious arrangement of the *fireplace*, and the *throat* and *flue* of a chimney, an upward current may be constantly ensured so long as there is a fire in the grate, or the air of the apartment is warmer than the external atmosphere.”

The coalfields of England are divided into three principal districts:—1. The Great Northern district, including all the coalfields north of the Trent. 2. The Central district, including Leicester, Warwick, Stafford, and Shropshire. 3. The Western district, subdivided into *North-western*, including North Wales, and the *South-western*, including South Wales, Gloucester, and Somersetshire. The principal coal-basins in Scotland are:—1. Ayrshire; 2. Clydesdale; and 3. The Valley of the Forth.—*Ure.*

It has been the custom with railway companies in France to introduce into their contracts for coke, conditions under which they are not liable for the water which “dry coke” contains, moreover, the proportion of ashes must not exceed 8 per cent., or the coke is refused. At one time, the manufacturers were enabled, by washing the coal, to sell coke containing only 6 or

7 per cent. of ashes. These cyphers have been established by the Northern Railway Company of France, which has all the cokes it employs submitted to regular examination as to the quantity of water and ash which they contain.

The bogs in Ireland occupy an extent little short of three millions of acres, and contain an inexhaustible supply of peat ; they vary extremely in depth in different localities ; neither the greatest depth nor the average depth of many of them has been ascertained. From a comparison of about thirty of them which were surveyed by Nimmo, Griffith, &c., it appears that the greatest depth varied from 47 to 13 feet, and the greatest average depth from 35 to 8 feet. The peat of these bogs differs much in composition ; but, besides its vegetable matter, it contains, in all cases, more or less saline and earthy substances, as gypsum and other salts, with a little ammonia.—*Edmund Davy*.*

M. de Marsilly observed that however pure a piece of coal may be, and however homogeneous it may appear, it does not leave by combustion the same proportion of ash in its various parts. It is the same with the coke furnished by the calcination of fragments of the same block of coal, from which it is concluded that coal must be reduced to very fine powder in order to find, in the same sample, the same amount of ash or coke.

Many years ago there was an important action at law in Scotland, the object of which was to determine whether or not a substance called *Boghead coal* or *Torbanehill mineral*, found in Bathgate, near Edinburgh, was coal in the proper sense of the term. The conflict of scientific opinion, which included that of

* *The Chemist*, page 718, Vol. II.

chemists, geologists, and mineralogists, was so great as to materially shake public confidence as to the infallibility of science, or rather her followers. While Professor Brande and others opined that the mineral was *not* coal, Professor Graham and other scientists declared that it *was* coal. Mr. Thornton J. Herapath, a chemist of high ability (who had not been engaged in the case), from a pure love of science, and with a desire to give the public an independent opinion, carefully examined the mineral, and came to this conclusion:—"That the boghead coal is, chemically speaking, a mineral *sui generis*, forming part of a series of substances which graduate into each other, and of which pit-coal, anthracite, and bitumen are the principal members. Regarded from a commercial point of view, however, it is undoubtedly a coal."

Whether coal is a mineralogical species or not is a question upon which some mineralogists hold different views. Mr. Highley says: * "They are unanimous, however, in regarding a crystal as the true natural history *individual*; but as minerals more frequently occur in a massive state, they have extended the idea to those homogeneous bodies which exhibit the same chemical constitution throughout their mass. From the time of Werner to the latest works on mineralogy, coal, though never found otherwise than in a massive state, has been classed in all systems as a mineralogical species.

"Professor Quekett has examined, by the aid of the microscope, a vast number of sections of coal from various localities as well as the Torbanehill mineral; and he proves that, while the Torbanehill mineral is a resinous-looking body, nearly homogeneous, and devoid of vegetable structure, coal, on the other hand, is almost entirely made up of woody fibre, and no

* *The Chemist*, New Series, Vol. I., 1854.

homogeneous in aspect, the interstices between the fibres being filled with a resinous body similar in appearance to the Torbanehill mineral. Having examined many varieties of coal taken at random from Professor Quekett's extensive series of horizontal and vertical sections, I come to the conclusion that coal is nothing more than fossil wood mineralised by bituminous or resinous matter, and that it holds the same relation to such bodies as wood opal does to *Opal*, and is, in fact, similar in character to any organic remains mineralised by silex, carbonate of lime, or other substances. Viewed in this light, *coal has no claim to a place in any Mineral System as a species*. If this be admitted, it will prove the necessity of submitting massive minerals to microscopical examination before their true character can be acknowledged, and before they can be admitted into any natural history classification."

The late Professor Crace-Calvert proposed the admixture of certain proportions of common salt with the coke used in locomotive and other engines, which had the effect of neutralising the injurious action of sulphurous vapours upon the copper of the fire-box and the tubes of the boiler.

St. James's Park was first lighted by coal-gas on August 23, 1821.

The proportions of carbon in the various kinds of coal and in peat are as follows:—Peat, 58·09; lignite, 71·77; splint coal, 82·92; cannel coal, 83·75; cherry coal, 84·84; caking coal, 87·95; and anthracite, 91·98. So that the latter, like plumbago, is almost pure carbon.

Small quantities of a great variety of substances are found interspersed through masses of coal in the different coalfields. *Ozokerit*, or fossil wax, is found in cavities in rocks lying upon

coal ; it is of a brown colour and presents a foliated structure, and fuses at 143° .

Carbon exists in large quantities, and is very extensively distributed in nature, as a constituent of all vegetable and animal bodies. It is found also in the mineral kingdom, under forms, however, which may be shown to have originally been derived from organic bodies. Thus, the different varieties of coal have been produced by the aggregation of great quantities of wood, the materials of primeval forests, which being submerged in water, and covered by the gradually deposited layers of sand and mud, have been elevated, in connection with the strata of clay and sandstone so produced, to their present situations. The wood thus circumstanced has undergone a kind of decomposition, and the mixture of fixed and volatile organic products which constitute our coal has thus its origin. This formation of coal, as well as the formation of peat and turf at the present day, almost at the surface, is accompanied by a disengagement of carbonic acid in large quantities, and hence the probable source, in the air and in mineral waters, of that substance, of which also much may be derived from the respiration of animals.—*Kane*.

The late Mr. Banister, in his admirable Treatise on *Gas Manipulation* (enlarged by Mr. W. Sugg), gives the following interesting observations concerning gas-burners, a subject of importance to most of us :—“ In referring to the various kinds of burners used for coal-gas, it must be remarked that the photogenic power of any luminiferous agent depends upon two conditions—*quantity* and *intensity*. By *quantity*, I mean that the carbonaceous particles of the flame are numerous ; by *intensity*, that they are highly heated. Now, the perfection of gas illumination consists in providing a burner so constructed

that these two conditions just balance each other. This subject appears to be very little understood by many burner makers. In fact, in some experiments made recently on 15-hole Argand burners, obtained from different establishments, I have found the illuminating power of 5 feet of gas to vary as much as 50 per cent., simply through the above conditions not being properly attended to. The oxyhydrogen lime light is an excellent example of *intensity*, the number of particles of carbon being very small, but the temperature to which they are heated is very high.

“The *quantity* of light from a solid-wick oil lamp is great, but the *intensity* is small. So that there may be great intensity where the quantity is small, or great quantity where intensity is small. If a straight wire be passed through the flame of a common candle there will be no increase of illuminating power, because the flame of the candle already contains more solid constituents than can be satisfactorily heated by the hydrogen of the tallow; whereas with Newcastle gas, burning from an ordinary burner, exactly the reverse is the case, because the hydrogen is in excess and the solid matter deficient. Now, if the colour of the flame from a well-constructed Argand burner be compared with that from a fishtail or batwing, it will be observed that the former is brown and the latter blue, which clearly shows that the quantity of light exceeds the intensity of the Argand, whereas with the batwing or fishtail the intensity exceeds the quantity. If the light produced from 5 feet of gas consumed in a 15-hole Argand burner be equal to 13 candles, the light from a similar quantity of gas consumed in a batwing or fishtail burner will not exceed 9 candles.”

There are no physical and chemical properties by which in

all cases a coal may be characterised as brown coal and distinguished from other kinds of coal. Coals from different formations are sometimes so similar in external character as to be confounded with each other. Thus, for example, at Malowka, in Russia, a carboniferous coal has been found which in parts wholly resembles brown coal in appearance, and, moreover, a comparatively recent one, so that it was only by accurate scientific investigation proved to belong to the carboniferous system. There is coal from the cretaceous formation, which appears to be identical with certain kinds of brown coal; and there is alluvial coal, nay, even peat, which exactly resembles varieties of brown coal. Hence, the relative age of coal can only be determined by the geological and palæontological conditions of its formation. —*Zincken*.

All coal contains more or less water, and this may be expelled by submitting the coal to a temperature a little over 212° Fahr. Even though coal may appear perfectly dry on its surface, if subjected to moderate heat for a considerable time, it will be found to have lost in weight. The water in coal is not derived from external moisture, but is inherent in the coal itself.

A comparison between the coal area of Europe and that of the United States of America shows greatly in favour of the latter as far as limit is concerned. The whole of Europe comprises a total area of 3,758,000 square miles, of which less than 10,000 square miles constitutes the coal-producing area. The total area of the United States territory is 3,000,000 square miles, and the coal-producing area is 200,000 square miles. The total territory of Great Britain is only 121,000 square miles, yet within this limited space she possesses more than half the coals of Europe.

The proportion of coal in Europe is about one square mile of coal to every 375 miles of territory, while the proportion of England is $\frac{1}{20}$, or one square mile of coal to every 20 square miles of territory; and the proportion of the United States is $\frac{1}{15}$, or one mile of coal to every fifteen of territory.

It is believed to be well proved that although coal was known as a fuel B.C. 351, its practical development was due to the ancient Britons before the Roman invasion; and the discovery of tools and coal cinders upon old Roman walls clearly shows that it was used by them.

Coal was first taxed by Government in 1379, and from that period up to 1831 many modifications took place, until, in the latter year, the tax was repealed, after having existed for about four hundred years.

The first patent for making iron with pit-coal was granted to one Simon Sturtevant in 1612, but this was not successful. Dudley next made an attempt in the same direction, but he lost all his property, and was subsequently imprisoned for debt. The next, but more successful, attempt to manufacture pig-iron in a blast furnace with pit-coal was made by a Mr. Darby, of Colebrookdale, in 1713. In 1747, cast-iron suitable for the manufacture of cannon was made with pit-coal.

An American writer says:—“The prosperity of England is involved in the duration of her coalfields. The exhaustion of her mines must sap the foundation of her strength. The subject engages the attention of her people, and all available measures are taken to economise this great and primary source of her prosperity and power.”

An English writer gives the following gloomy picture as the

result of our using up all our coal :— “ Without coal our steam-power would be annihilated, and with that our prosperity as a nation, and possibly our supremacy. Our steam-engines would rust unused for lack of suitable fuel ; our steamships would be dismantled and decaying in dock, and all our processes of manufacture would be deteriorated ; and the future historian of the revolutions of empires would date the decline and fall of the vast domains of Britain from the period when her supplies of mineral fuel were exhausted and her last coalfield worked out.”

One of the latest discoveries in connection with aniline dyes, is their production, from aniline salts, by means of the electric current. This has been accomplished by M. Gœppelsrøder, who is able to form, and fix, aniline dyes within the fibres of cloth and other fabrics by electricity. The cloth is placed between two metal plates (on one of which is a raised pattern), and steeped in a solution of the aniline salt to be decomposed. The plates are then connected to the positive and negative poles of a voltaic battery, or dynamo-electric machine, when the solution becomes decomposed by the current, and those parts of the fabric in contact with the raised design become dyed of any desired shade or colour.

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